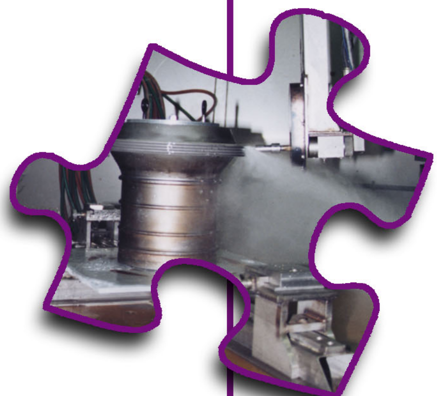
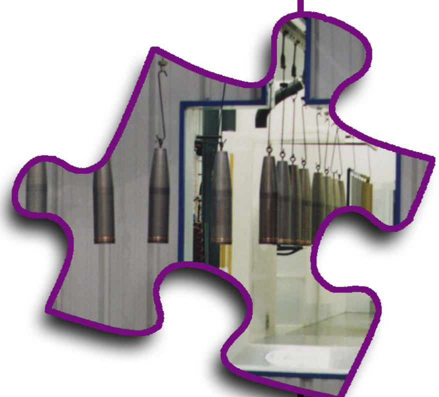
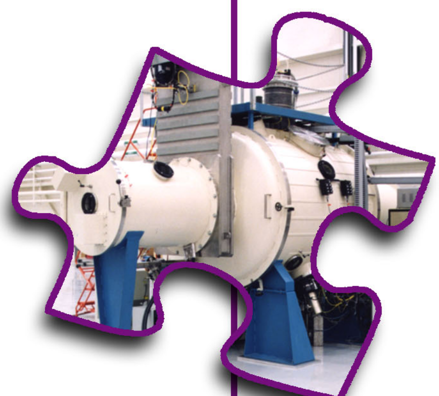
NDCEE

ANNUAL TECHNOLOGIES PUBLICATION





April 2003



National Defense Center for Environmental Excellence

Executive Agent

Office of the Assistant Secretary of the Army
(Installations and Environment)

Table of Contents

Acronyms & Abbreviations

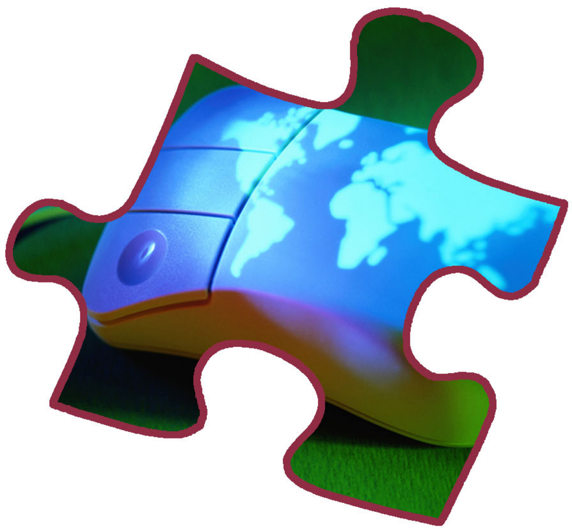
AAP	Army Ammunition Plant
ACI	Advanced Cerametrics, Inc.
AEC	U.S. Army Environmental Center
AERTA	Army Environmental Requirements and Technology Assessments
AFB	Air Force Base
AFRL	Air Force Research Laboratory
ALC	Air Logistics Center
ANAD	Anniston Army Depot
APTI	Advanced Power Technologies Inc.
B&L	Bouldin & Lawson
CCAD	Corpus Christi Army Depot
CEG-A	Combat Equipment Group-Afloat
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERL	Construction Engineering Research Laboratory
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
COR	Contracting Officer's Representative
CRADA	Cooperative Research and Development Agreement
CrN	Chromium nitride
CRT	Cathode ray tube
CTC	Concurrent Technologies Corporation
DARPA	Defense Advanced Research Projects Agency
DC	Direct current
DCC-W	Defense Contracting Command-Washington
DEER2	Demanufacturing of Electronic Equipment for Reuse and Recycling
DLA	Defense Logistics Agency
DLC	Diamond-like carbon
DoD	Department of Defense
DP	Differential pressure
DRE	Destruction and Removal Efficiency
DRMS	Defense Reutilization and Marketing Service
DU	Doppler Ultrasonic
ECAM^{SM}	Environmental Cost Analysis Methodology
ECCP	Electrically conducting composite pipes
EDTA	Ethylene diamine tetra-acetic acid
EHC	Electroplated hard chromium

EIS	Electrochemical impedance spectroscopy
EL	Ethyl lactate
EN	Electroless nickel
ENP	Electroless nickel-phosphorus
EPA	U.S. Environmental Protection Agency
ERDC	U.S. Army Engineer Research Development Center
ESD	ElectroSpark Deposition
FBG	Fiber Bragg Grating
FC*Tec*	Fuel Cell Test and Evaluation Center
FDR	Frequency domain reflectometry
FMD	Flow-measuring device
FY	Fiscal year
GAC	Granular activated carbon
H_2	Hydrogen
H_2O_2	Hydrogen peroxide
HAP	Hazardous air pollutant
HCFC	Hydrochlorofluorocarbon
HMMWV	High-Mobility Multipurpose Wheeled Vehicle
HMX	Cyclotetramethylene-tetranitramine
HVLP	High-volume low-pressure
HVOF	High velocity oxy-fuel
IAAAP	Iowa Army Ammunition Plant
IBAD	Ion beam assisted deposition
ICP	Instrumented cathodic protection
IEC	Industrial Ecology Center
IRR	Internal rate of return
IVD	Ion vapor deposition
IWTP	Industrial Wastewater Treatment Plant
JG-PP	Joint Group on Pollution Prevention
JTP	Joint Test Protocol
kW	Kilowatt
LCAAP	Lake City Army Ammunition Plant
LISI	Laser-Induced Surface Improvements
LPR	Linear polarization resist
MACOM	Major Command
MEMS	Micro-electromechanical system
MFH	Military Family Housing
MLAAP	Milan Army Ammunition Plant

Mo	Molybdenum
MRF	Materials Recovery Facility
MSW	Municipal solid waste
NA	Not applicable
NADEP-JAX	Naval Air Depot, Jacksonville
NAVAIR	Naval Air Systems Command
NC	Nitrocellulose
NDCEE	National Defense Center for Environmental Excellence
NDT	Nondestructive technique
Ni	Nickel
NLOS	Non-line-of-sight
NNSY	Norfolk Naval Shipyard
NOCS	Navy Oxygen Cleaning System
NPDES	National Pollutant Discharge Elimination System
NPV	Net present value
NSWCCD	Naval Surface Warfare Center, Carderock Division
OC-ALC	Oklahoma City Air Logistics Center
ODASA(ESOH)	Office of Deputy Assistant Secretary of the Army (Environment, Safety, and Occupational Health)
ODS	Ozone-depleting substance
OSHA	Occupational Safety and Health Administration
PACVD	Plasma-assisted chemical vapor deposition
PCCP	Prestressed concrete cylindrical pipe
PCMS	Passive countermeasure system
PEO	Polyethylene oxide
PHNSY	Pearl Harbor Naval Shipyard
PMB	Plastic media blasting
psi	Pounds per square inch
psig	Pounds per square inch @ gauge
PSNS	Puget Sound Naval Shipyard
PVD	Physical vapor deposition
PWCS	Process water collection system
RAID	Remote Acoustic Impact Doppler
RCRA	Resource Conservation and Recovery Act
RDX	Cyclotrimethylene-trinitramine
REDMAP	Radford Environmental Development and Management Program
RF	Radio frequency
RFAAP	Radford Army Ammunition Plant

RIA	Rock Island Arsenal
RO	Reverse osmosis
SAC	Strong acid cationic
SAFR	Small arms firing range
SARA	Superfund Amendments and Reauthorization Act
SBA	Strong base anionic
$SCCO_2$	Supercritical carbon dioxide
SERDP	Strategic Environmental Research and Development Program
SHT	Special hull treatment
SIC	Sentient Instrument Controller
SIMA	Shore Intermediate Maintenance Activity
TACOM	U.S. Army Tank-automotive and Armaments Command
TACOM-ARDEC	U.S. Army TACOM - Armament Research, Development & Engineering Center
TARDEC	U.S. Army Tank Automotive Research, Development and Engineering Center
TBP	Thermophilic (Biological) Process
TCP	Trivalent chromium pretreatment
3-D	Three-dimensional
TNT	2,4,6 trinitrotoluene
TTU	Transit-Time Ultrasonic
TYAD	Tobyhanna Army Depot
UF	Ultrafiltration
UHPWJ	Ultrahigh-pressure waterjet
U.S.	United States
USDA	U.S. Department of Agriculture
UV	Ultraviolet
VOC	Volatile organic compound
W	Tungsten
WAC	Weak acid cationic
WBA	Weak base anionic
WIU	Wiring Integration Unit
WPAFB	Wright-Patterson Air Force Base

OVERVIEW



NDCEE

the missing piece to today's environmental solutions

Introduction

In 1991, the U.S. Congress established the National Defense Center for Environmental Excellence (NDCEE) as the national resource for developing and disseminating advanced environmental technologies. Since that time, the NDCEE has provided technology evaluation, verification, implementation and other services to hundreds of Department of Defense (DoD) installations, DoD prime contractors, other government agencies and industry.

The NDCEE is focused on end-user needs and achieving specific performance-based results. It helps speed up technology development and deployment while integrating environmental decisions into the life cycle of a weapons system. It also ensures that technologies are implemented efficiently and effectively, using benchmarking and appropriate metrics.

The NDCEE emphasizes risk reduction, cost savings, enhanced readiness and environmental excellence by:

- Focusing on pollution prevention activities that have positive financial impacts
- Demonstrating technologies through an approach that rapidly validates and transitions technologies.

Technology transition is the ultimate measure of success and is the positive outcome of technology evaluation and verification. To date, over 100 transitions and/or demonstrations of tangible technologies have been completed or scheduled. These technologies include manufacturing materials and processes, environmental treatment and control devices, and site assessment and clean-up technologies. In addition, more than 80 technology tools have been developed and transitioned by the NDCEE. Examples of such tools include training, environment cost analyses, lessons learned databases, geographical information systems, risk analyses and information exchanges.

This first *NDCEE Annual Technologies Publication* is submitted in fulfillment of Contract Data Requirements List requirement A005 for the NDCEE Contract DAAE30-98-C-1050, Task No. 300, “NDCEE Mission Support.” This document contains the results of the NDCEE’s technology demonstration and transition activities in fiscal year (FY) 2002. Where applicable, FY01 activities have also been included to provide an up-to-date account of the NDCEE’s involvement with a particular technology.

During FY02, the NDCEE addressed 43 technologies. A summary on each technology has been created that describes the technology; its benefits and advantages; its limitations; specific FY01 and FY02 NDCEE accomplishments; NDCEE economic analysis findings (if applicable), including capital and operating cost estimates as well as payback periods; suggested implementation applications; points of contact; and applicable NDCEE tasks.

To aid readers in identifying technologies that may solve their specific challenges, each summary features a box that states a generic DoD need that the technology addresses. Also identified are the Services’ specific high-priority needs. The referenced codes for the U.S. Air Force and Navy were obtained from the DoD’s *Draft Environmental, Safety and Occupational Health High Priority Environmental Technology Requirements Report*, dated April 2001. The U.S. Army’s codes were obtained from the *Army Environmental Requirements and Technology Assessments* (AERTA), dated October 29, 2001.

In conjunction with the above technology activities, the NDCEE operates a Demonstration Facility. This facility is described on page 103. Immediately following the facility description are summary sheets on each of the facility’s technologies.

Collaborative Relationships

Collaborative relationships are an integral component to the NDCEE's success at identifying, demonstrating, validating and implementing solutions for clients. From the onset of a task, the NDCEE works intimately with the client to understand the client's unique concerns, challenges and needs. Wherever appropriate, the NDCEE also collaborates with other entities in the quest for a cost-effective, technically viable solution that is most appropriate for a client's unique circumstances.

During FY02, the NDCEE worked with a wide variety of organizations within the DoD. The NDCEE also worked with other federal agencies, academic institutions and private industry. More than 50 of these entities, listed below, were involved with the technology activities featured within this document.

Aberdeen Test Center, Aberdeen Proving Ground, Maryland

Air Force Research Laboratory (AFRL), Aberdeen Proving Ground, Maryland

Anniston Army Depot (ANAD), Alabama

Army Environmental Center (AEC), Aberdeen Proving Ground, Maryland

B-1, B-2, F-15, and F-16 weapon system personnel

Corpus Christi Army Depot (CCAD), Corpus Christi, Texas

Defense Advance Research Planning Agency (DARPA)

Defense Contracting Command - Washington (DCC-W), Washington, DC

Defense Logistics Agency (DLA)

Defense Reutilization and Marketing Service (DRMS)

Fort Benning, Georgia

Fort Bragg, Fayetteville, North Carolina

Fort Dix, New Jersey

Fort Eustis, Virginia

Fort Hood, Texas

Fort Lewis, Lakewood, Washington

Fort Ord, California

Fort Story, Virginia

Indian Head Naval Surface Warfare Center, Maryland

Industrial Ecology Center (IEC), Picatinny Arsenal, New Jersey

Iowa Army Ammunition Plant (IAAAP), Middletown, Iowa

Joint Group on Pollution Prevention (JG-PP)

Lake City Army Ammunition Plant (LCAAP), Independence, Missouri

Lawrence Livermore National Laboratory, Livermore, California

Marine Corps Logistics Base, Yermo Annex, Barstow, California

Milan Army Ammunition Plant (MLAAP), Tennessee

Natick Soldier Center, Natick, Massachusetts

Naval Air Systems Command (NAVAIR)

Naval Aviation Depot - Jacksonville (NADEP-JAX), Florida

Naval Aviation Depot - Cherry Point, North Carolina

Naval Aviation Depot - North Island, California

Naval Surface Warfare Center, Carderock Division (NSWCCD), West Bethesda, Maryland

New Mexico State University - Physical Science Laboratory, Las Cruces, New Mexico

Norfolk Naval Shipyard (NNSY), Virginia

Office of Deputy Assistant Secretary of the Army (Environment, Safety, and Occupational Health [ODASA(ESOH)], Washington, D.C.

Office of Naval Research

Ogden Air Logistics Center, Utah

Oklahoma City Air Logistics Center (OC-ALC), Tinker Air Force Base, Oklahoma

Patuxent River Naval Air Warfare Center, Aircraft Division, Maryland

Pearl Harbor Naval Shipyard (PHNSY), Hawaii

Presidio of Monterey, California

Puget Sound Naval Shipyard (PSNS), Seattle, Washington

Radford Army Ammunition Plant (RFAAP), Virginia

Rock Island Arsenal (RIA), Illinois

Sandia National Laboratory, Albuquerque, New Mexico

Schofield Barracks, Hawaii

Shore Intermediate Maintenance Activity (SIMA) Mayport, Florida

Tobyhanna Army Depot (TYAD), Pennsylvania

University of California, Santa Cruz, California

U.S. Army Combat Equipment Group-Afloat (CEG-A), Goose Creek, South Carolina

U.S. Army Engineer Research Development Center/Construction Engineering Research Laboratory (ERDC/CERL), Champaign, Illinois

U.S. Army Tank-automotive and Armaments Command - Armament Research, Development & Engineering Center (TACOM-ARDEC)

U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC), Warren, Michigan

U.S. Department of Agriculture (USDA)

U.S. Environmental Protection Agency (EPA)

TARDEC Fuels and Lubricants Research Facility, San Antonio, Texas

Wright-Patterson Air Force Base (WPAFB), Ohio

NDCEE Technology Transition Methodology

Over the past decade, the NDCEE has developed and implemented a six-step Technology Transition Methodology that focuses on reducing the technical, cost, schedule and regulatory risks associated with implementing technologies. This methodology facilitates a technology's evolution from research, development, testing, and evaluation to fielding and complements the technology transfer activities managed by the Services, such as those under the Army's Environmental Quality Technology (EQT) Program. As shown in the schematic, these steps are:

1. Baseline Analysis
2. Identify Alternatives
3. Technology Demonstration
4. Technology Justification
5. Technology Implementation
6. Follow-up

All of the technologies featured in this publication are beneficiaries of the NDCEE methodology. Depending on the task involved, only one or a few of these steps may have been utilized. In other cases, all six steps were applied to ensure that risks were reduced to a client-acceptable level.

NDCEE Technology Transition Methodology

Baseline Analysis
Working with the client, the NDCEE develops a performance specification that details client requirements. Typically, these requirements are determined by establishing a baseline of the current process and materials and considering the problems of the current process as well as future environmental requirements.

Identify Alternatives
Using the specification developed in the first step, the NDCEE identifies and evaluates technologies that have the potential to meet the requirements. The findings and recommendations are documented in a report.

Technology Demonstration
The NDCEE conducts demonstrations on the technology candidates to collect information on the technologies' ability to meet specified requirements. Specifically, data on performance, cost, predictability, and environment, health and safety risk are collected.

As part of the demonstration process, the NDCEE produces a test plan that includes provisions for feasibility, optimization and validation testing. Feasibility testing is low-cost, surrogate testing used to determine a technology's potential for meeting requirements. It is typically performed to eliminate (before incurring high testing costs) those technologies with a low probability of meeting requirements. Optimization testing is used to define the operating conditions to meet performance requirements. Full-scale validation testing is typically performed either on site under actual service conditions or in the NDCEE Demonstration Facility under simulated service conditions. Validation testing is used to determine if the process is statistically robust (i.e., will meet performance requirements under typical service conditions) and to collect data to support cost, performance and risk analysis. All of the test results are documented in a test report.

Technology Justification

As part of its recommendation process, the NDCEE conducts a technical, economic and regulatory assessment of the candidate technologies to determine the most appropriate technology for meeting client requirements. To be a viable replacement for the DoD, the new process has to meet or exceed existing performance and operational requirements as well as be cost effective and meet current and future regulations.

An economic analysis is provided as part of the NDCEE approach for every demonstration and validation task conducted wherein the technology technical requirements are met or exceeded. This proven approach minimizes the need for cost-benefit justification studies in which the technical requirements are not first satisfied.

Cost-benefit analysis is the evaluation and comparison of capital investments and operating cost benefits. Weighing the cost of a proposed investment against the benefits (economic, qualitative, etc.) that are expected to be derived from that investment can aid in the decision-making process. Utilizing its Environmental Cost Analysis Methodology (ECAM℠) tool, demonstration results, assumptions, and other relevant information, the NDCEE determines the payback period, net present value (NPV), and internal rate of return (IRR) for each technology. The ECAM℠ process utilizes activity-based costing methods and techniques to realistically analyze and assign such costs for new or modified manufacturing technologies. It contains tools for process mapping; assessing labor, material and utility resource requirements; and performing financial analyses of selected projects.

Compliance with Executive Orders and state and federal regulations are another consideration in the justification process. In many instances, the driver for technology implementation is improved environmental regulatory compliance. Failure to comply with environmental regulations [e.g., exceeding regulatory limits on ozone-depleting substances (ODSs), volatile organic compounds (VOCs), and/or hazardous air pollutants (HAPs)] could result in large public relations costs and fines. Adverse publicity cannot be easily quantified, but it could be the most damaging result for the DoD. Examples of potentially applicable regulations include the Clean Air Act; Clean Water Act; Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Resource Conservation and Recovery Act (RCRA); and Superfund Amendments and Reauthorization Act (SARA).

Technology Implementation

The NDCEE supports the full-scale implementation of the selected technology, providing support in appropriate areas such as technology procurement, installation startup and operator training.

Follow-Up

The NDCEE will monitor the implementation for a period of time after startup to ensure a technology's proper and effective use.

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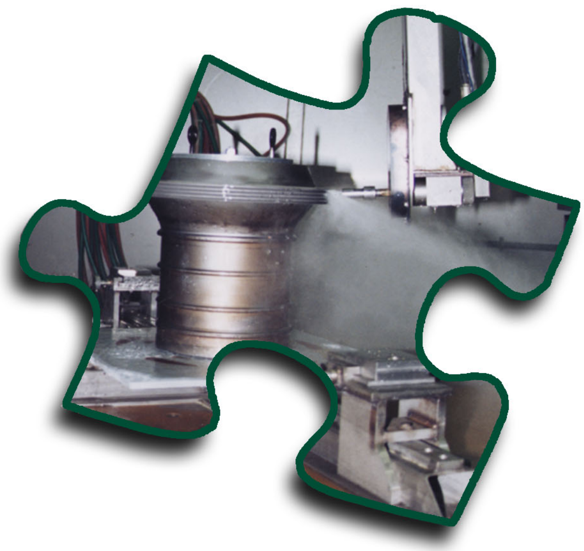
TECHNOLOGIES



NDCEE

the missing piece to today's environmental solutions

Automated Acid Sampling System

The NDCEE implemented an Automated Acid Sampling System at Radford Army Ammunition Plant. This process improvement was based on findings from an NDCEE engineering review of the nitration process at RFAAP. The nitration process, which uses both nitric and sulfuric acids, is a major contributor of the acids that must be processed through the wastewater treatment facility. The goal was to reduce the amount of acid being treated at the wastewater treatment facility by reducing acidic discharges from the nitrocellulose (NC) line. NC is produced on site at RFAAP and used as a base material in the manufacture of single-, double- and triple-based propellants.

Technology Description

The automated acid sampling system is an alternative to the manual collection and subsequent disposal of sample solutions. The system features a set of in-line measuring devices (mass/flow meters) that are located in the acid sampling lines. The devices are remotely monitored at a central location.

Previously, RFAAP ensured proper operation of the nitration process by manually collecting samples on a regular basis and measuring the specific gravity. Based on the measurements, operators determined whether the acid mixture was acceptable or whether modifications were required to bring it within specific gravity specifications. After these samples were collected and measured, the sample solution was discharged to the wastewater treatment facility.

The NDCEE has installed 10 in-line measuring devices on the acid sampling lines of the nitration process. These devices allow in-line measurements to be performed on a regular and frequent basis. Results are presented on a display screen where operators can monitor the solution's specific gravity to determine if and when modifications to the acid mixture are required. By eliminating the acid waste stream created by manual measurements, the automated process is providing savings through lower treatment costs and increased productivity.

DoD Need

Improved Munitions Manufacturing Processes

Army: CM-10, CM-5, P2-5

Technology Benefits and Advantages

- Improves safety and worker health conditions
- Increases productivity
- Decreases acid waste by eliminating the need for manual measurements
- Reduces waste treatment costs

Technology Limitations

- Requires calibration and maintenance

NDCEE FY01 & FY02 Accomplishments

Based on a previously conducted engineering review of RFAAP's NC line, the NDCEE installed an automated acid sampling system. This system consists of 10 in-line measuring devices that are remotely monitored by RFAAP personnel.

Economic Analysis

The implementation cost for the new technology at RFAAP was approximately $133,000 and the estimated cost savings are approximately $103,000 per year. The expected payback period for implementing the technology was less than two years.

An automated acid monitoring system was installed in RFAAP's acid area (in photo).

Suggested Implementation Applications
DoD facilities engaged in propellant manufacturing operations are candidates for implementation.

Points of Contact
- Robert Davie, RFAAP, (540) 639-7612, Robert_Davie@atk.com
- Nelson Colon, IEC, (973) 724-2482, ncolon@pica.army.mil
- David James, NDCEE, (814) 269-6455, james@ctcgsc.org

Applicable NDCEE Task
Radford Environmental Development and Management Program (REDMAP) (Task N.225)

Automated Groundwater Sampling and Analysis System

The NDCEE is assisting the U.S. Army with facilitating clean-site closure for the purpose of property transfer and land development for civilian use. As part of its assistance, the NDCEE deployed and tested an automated groundwater sampling and analysis system at two sites at the former Fort Ord. In conjunction with this effort, the NDCEE conducted three-dimensional (3-D) characterization of the distribution and properties of the shallow aquifers and confining layers underlying and surrounding the Fort Ord landfill. It also developed a 3-D hydrostratigraphic model of the unconfined aquifer. Data from the model are used as input for generating numerical grids for groundwater flow and transport simulations, which are used to test VOC-source hypotheses, understand controls on groundwater flow, and predict future groundwater flow and transport behavior.

Technology Description

The groundwater sampling and analysis system conducts automated, real-time field analysis of groundwater to determine contaminants. Depending on the compound in question, concentrations can be measured 0.43–40 parts per billion. Inorganics can be sampled with a vial manifold for off-line analysis. The system also includes thermal groundwater flow sensors, deployed in groundwater wells, that are remotely monitored.

The NDCEE installed the system at Fort Ord in collaboration with Fort Ord, Presidio of Monterey, University of California Santa Cruz, Lawrence Livermore National Laboratory, and Lawrence Berkeley National Laboratory. In 1999, five new wells were drilled at Fort Ord and equipped with thermal flow sensors. The sensors are 3-foot-long cylindrical heaters that are studded with an array of 30 precision thermistors. The heaters dissipate around 70 Watts, heating the surrounding formation and groundwater. The flow of water around them cools the upstream side and warms the downstream; a similar perturbation in the vertical dimension detects any vertical component of flow. A mathematical inversion technique is used to back-calculate flow azimuth and vertical flow vectors.

In addition to the flow sensors, each of the new wells was equipped with a bladder pump and pressure transducer to measure water depth. Five additional, existing monitoring wells at the site were also equipped with pressure sensors and dedicated pumps. Using buried conduit that also contains signal lines from all of the sensors, the pumps feed water samples continuously to a centrally located analytical station. Burial of the conduit yielded an environmentally rugged, yet visually appealing installation of monitoring equipment.

DoD Need

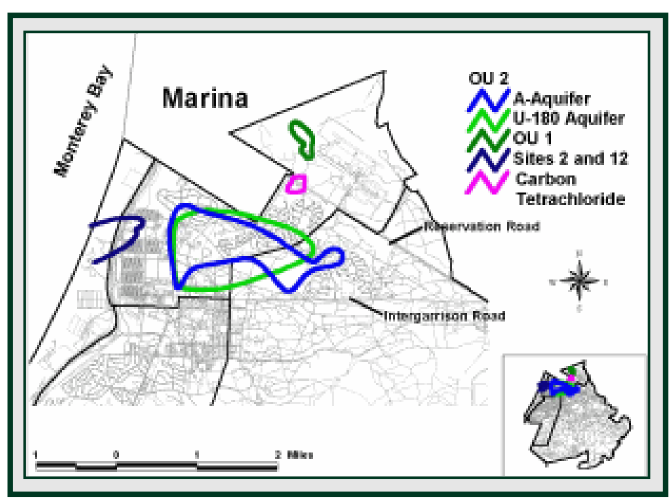
Improved groundwater monitoring techniques

Army: R-5

Air Force: 124, 1608

Navy: 1.II.01.a, 1.III.02.a, 1.III.02.k

At the analytical station, water samples are taken for real-time automated analysis with a customized sample selection and preparation system, and analyzed for VOCs by purge and trap gas chromatography using methods based on standard EPA protocols. In addition, prior to each sample being processed for VOCs, a 40-milliliter sampling vial is flushed with sample water; these samples can be removed at any time and stored for off-site analyses, such as ion chromatrography for inorganic tracers.



Groundwater plumes at the former Fort Ord

Technology Benefits and Advantages

- Analyzes groundwater samples automatically in real-time
- Enhances remediation efforts

- Monitors for an array of contaminates, including metals and VOCs
- Detects organochlorine and aromatic contaminants at the parts per billion level
- Contains samples of high integrity, never contacting air, and traveling only through stainless steel lines before analysis
- Reveals greater contaminant spatial distributions than those estimated with conventional sampling and remote analysis, providing deeper insights into the function of remedial operations

Technology Limitations

- VOC analyses in conventional analytical laboratories generally incorporate internal standards, and surrogate compounds, to improve precision and provide sample-by-sample recovery data. The present system relies exclusively on external standards and has not included surrogates. Provision for these parameters would bring the analytical methods into greater congruity with contract laboratory procedures.

NDCEE FY01 & FY02 Accomplishments

- Refined online instrumental analytical tools to evaluate their operational utility and regulatory acceptance (FY01)
- Finalized implementation of a Hydrological Field Station at the former Fort Ord site (FY02) (Known as Operating Unit 1, the station offers a number of attractive features for hydrological analysis, tracer-transport tests, and demonstration of new environmental remediation technologies.)
- Produced a Final Report that summarized the activities and findings associated with the groundwater system and other Fort Ord activities, including ecological activities that addressed issues related to threatened and endangered plant species (FY02)
- Continued maintenance of the Fort Ord Web site (www.fortordcleanup.com/), which was developed by the NDCEE in FY99 as a community-relations tool (ongoing)

Economic Analysis

The NDCEE conducted a cost-benefit analysis of the use of treated groundwater at Ford Ord. Five options were identified based on technical feasibility and the existing and near-term need for treated groundwater. The analysis findings showed that treated groundwater use as either residential drinking water or agricultural use provided favorable returns on investment and payback periods of less than two months. However, the most probable public relations option was for agricultural use. Use of the treated groundwater for landscaping or recreational purposes was not economically viable.

The NDCEE did not conduct a cost-benefit analysis on the implementation of the groundwater sampling and analysis system. However, the system is expected to reduce remediation processing time and therefore reduce overall costs. The actual hardware costs for the integrated flow monitoring and analytical chemistry station were approximately $400,000; future installations of comparable size could be constructed for somewhat lower cost, given the design experience gained in the Fort Ord project.

Suggested Implementation Applications

The new groundwater system can be deployed at other DoD installations, particularly to Formerly Used Defense Sites and Base Realignment and Closure Commission sites, with groundwater monitoring concerns.

Points of Contact

- Gail Youngblood, Fort Ord, (408) 242-1562, youngbloodg@pom-emh1.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Dr. Bashar Alhajjar, NDCEE, (619) 725-5003, alhajjar@ctcgsc.org

Applicable NDCEE Task

Environmental Restoration Demonstration (Fort Ord Landfill - Phase II) (Task N.281)

Automatic Corrosion Inhibitor Application System for Army Tactical Vehicles

The NDCEE is identifying, investigating and developing environmentally friendly technologies that can be used to measure, control and prevent corrosion. The NDCEE has designed and installed a prototype Automatic Corrosion Inhibitor Application System for Army Tactical Vehicles. This facility will be used to optimize the final facility design and processing variables, allowing formal specifications and operating procedures to be generated. The findings will be applied to construct and operate new corrosion inhibitor application facilities at U.S. Army shipping locations, maintenance facilities and depots.

Technology Description

The Automatic Corrosion Inhibitor Application System for Army Tactical Vehicles automatically cleans vehicles and then applies a corrosion inhibitor for metal protection. The system was developed to relieve operators from manually applying the inhibitor to tactical ground vehicles prior to shipboard transportation. The manual application process is time-consuming and costly, particularly as the inhibitor must be reapplied every six months to assure continued protection.

The NDCEE designed and installed a prototype facility at Fort Hood. Vehicles are driven into the facility and undergo an automatic wash cycle in preparation for the corrosion inhibitor application. The vehicles then reenter the facility to receive the corrosion inhibitor, which is applied using the same spray equipment as the automated wash operation. All liquids are recycled using a closed-loop system.

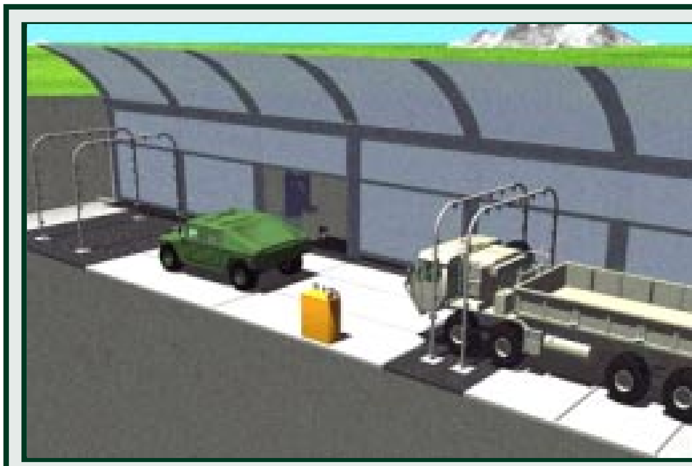
Corrosion inhibitors work by bonding to a metal surface to form a microscopically thin continuous layer. This layer becomes a barrier between the metal and the corrosive environment. The sprayed-on liquid corrosion inhibitor utilized by the prototype facility was selected based on recommendations from the Army Research Laboratory, which had evaluated several commercial corrosion prevention products.

Technology Benefits and Advantages

- Is a modular system that can be configured to treat a variety of vehicle sizes and meet the required throughput
- Utilizes commercial-off-the-shelf equipment to both wash the vehicles and apply a corrosion inhibitor in less than half of the time associated with the manual application process
- Prevents the formation of corrosion in vehicles
- Improves mission readiness through reduced risk of vehicle failure
- Reduces maintenance costs associated with corrosion protection of ground vehicles
- Reduces discharges to industrial waste water treatment plants through a closed-loop system
- Has flexibility in design of inhibitor application facilities, which are nonintrusive to host site (system may be relocated as needed or incorporated into maintenance and logistics facilities)

DoD Need

Corrosion prevention in tactical vehicles



Inside view of an Automatic Corrosion Inhibitor Application System for Army Tactical Vehicles

Technology Limitations

- System is still undergoing testing. Operating procedures still need to be evaluated for efficiency.
- Regulatory permits may be required.

- Facilities will require access to utilities, such as water and electricity.
- Additional space is needed for staging and curing areas, depending on expected throughput.

NDCEE FY01 & FY02 Accomplishments

- Designed, procured and installed a demonstration/validation facility at Fort Hood (FY02)
- Began demonstration/validation phase of the facility (FY02)
- Began environmental assessment of the facility (FY02)

Economic Analysis

Corrosion has a significant impact on the readiness, reliability and cost of ownership of weapons systems, support equipment and infrastructure. The estimated cost of corrosion to the DoD is $400 million per week, of which approximately one third is avoidable through the use of new and improved corrosion prevention or control techniques.

Prototype Automatic Corrosion Inhibitor Application Facility Under Construction at Fort Hood

An estimated total investment of approximately $270,000 is necessary to acquire equipment comparable to that which is installed at Fort Hood. The corrosion inhibitor is approximately $1,000 per 55-gallon drum, with an estimated 1 gallon of product used per vehicle. Other operational costs include utilities, labor, alkaline detergent, petroleum-decomposing enzymes and personal protective equipment.

Suggested Implementation Applications

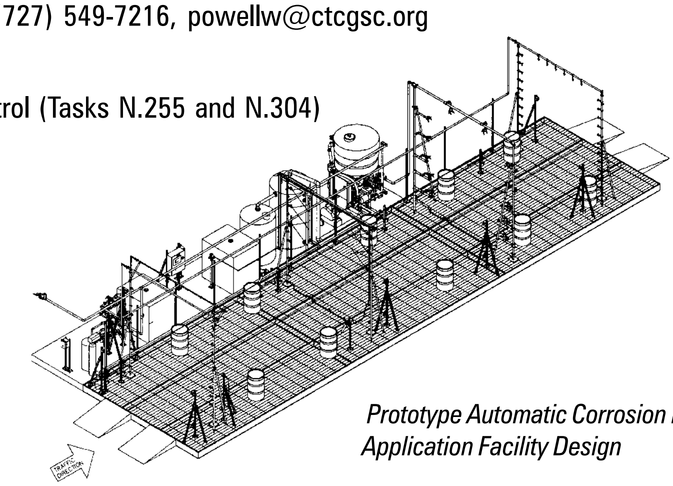
This technology can be installed at any maintenance facility or rapid deployment site used for trans-oceanic transports. The system was designed for use by all-wheeled tactical vehicles and ground support equipment.

Points of Contact

- Tom Landy, TACOM-ARDEC, (586) 574-8818, landyt@tacom.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Wayne Powell, NDCEE, (727) 549-7216, powellw@ctcgsc.org

Applicable NDCEE Tasks

Corrosion Measurement and Control (Tasks N.255 and N.304)



Prototype Automatic Corrosion Inhibitor Application Facility Design

Bio-Based Hydraulic Fluids

The NDCEE, in conjunction with TARDEC and the TARDEC Fuels and Lubricants Research Facility, is identifying, testing, and evaluating bio-based hydraulic fluids for use in military equipment for DLA. The NDCEE evaluation, including working with industry leaders in bio-based hydraulic fluid development, will facilitate establishing performance levels for bio-based hydraulic fluids. The USDA will use project findings to assist in establishing bio-based content ranges and definitions for future procurements of new bio-based products.

Technology Description

Bio-based hydraulic fluids are derived from renewable plant resources and are generally more environmentally benign than their petroleum-based and synthetic counterparts. Hydraulic fluids, under pressure, transmit power to moving parts of many machines and equipment, including tanks, airplanes, cars, bulldozers, tractors, and most heavy equipment. Although presently formulated for commercial usage, the new bio-based fluids are being developed to meet more stringent military specifications.

All hydraulic fluids contain ingredients that reduce wear, enable the fluid to flow better, and make it thinner in colder temperatures. They also have a high flash point for safety as well as antirust and antioxidation properties. Traditionally, petroleum-based fluids have been used because they are inexpensive and plentiful. Bio-based fluids are biodegradable, require fewer additives and may perform better under heavier loads. They are becoming more readily available and less expensive.

For the NDCEE evaluation, TARDEC identified 10 target performance properties based on two demanding synthetic (MIL-PHF-46170) and petroleum-based (MIL-PRF-6083) hydraulic fluid military specifications for combat tactical vehicles. The specifications require cold temperature performance below -76°F (-50°C) and flash points above 392°F (200°C). In addition, candidate bio-based lubricants were required to have a minimum bio-based content of 25%, and all of them exceeded that requirement. Testing is in progress. Fluids that meet or exceed requirements will be proposed for further individual component and equipment testing.

DoD Need

Develop environmentally compatible lubricants and fluids

Army: P2-13

Navy: 3.1.10.b

Technology Benefits and Advantages

- Is biodegradable, nontoxic and nonflammable
- Provides greater operator safety than conventional hydraulic fluids
- Reduces cleanup liabilities associated with spills and leaks of conventional hydraulic fluids
- Offers a better cost and performance profile than current products for many applications
- Helps DoD comply with Executive Orders 13101, 13123, 13134, 13148 and 13149 as well as RCRA and other regulations
- Is commercially available

Technology Limitations

- Although these fluids are commercially available, fluids that can meet military requirements for combat tactical vehicles are still in development.

The DoD intends to switch to bio-based hydraulic fluids for combat tactical equipment, such as this Bradley Fighting Vehicle (foreground), M1A2 Abrams Main Battle Tank, and Landing Craft (in water), which currently use petroleum-based or synthetic hydraulic fluids.

NDCEE FY01 & FY02 Accomplishments

- Produced a Requirements Report that documented efforts to identify USDA and military "standards" regarding the testing and validation of bio-based hydraulic fluids for intended applications (FY01). Sixteen candidates were submitted (Part A).
- Conducted a laboratory analysis to determine whether products could meet the established military requirements (FY01/02). Although Part A candidate results were promising, none passed all of the DoD target performance requirements. Based on Part A laboratory findings, ten candidates were reformulated (Part B) and submitted for additional laboratory testing. In the Part B analysis, two of the reformulated fluids passed 8 and two others passed 7 out of 10 of the requirements, with all four very narrowly missing passing all of the target requirements. The vendors have indicated that reformulation based on the Part B results will likely lead to meeting all 10 target requirements. Laboratory results are contained in Parts A and B of the Alternative Report (FY02).
- Produced Demonstration Plan for future field-testing activities (FY02). Future field trials will use military equipment at a U.S. Army installation and a U.S. Navy and/or Air Force base.

Economic Analysis

Many types of petroleum-based hydraulic fluids contain constituents that are considered toxic or hazardous. As a result, leaking equipment can contaminate soils, groundwater and surface water, polluting sensitive ecosystems where military maneuvers are conducted. Besides the incalculable costs to wildlife and their environment, restoration of fluid-contaminated sites can be costly to the Army, Air Force and Navy.

The NDCEE conducted a life-cycle cost analysis that took into account purchasing, waste disposal and spill costs. The current baseline costs for the purchasing and disposal of MIL-PRF-6083 and MIL-H-46170 hydraulic fluids are $9.28 and $13.88 per gallon, respectively. A spill event would add approximately $68 per gallon to those costs. These figures are derived from actual use and purchase data for Sandia National Laboratory. Biobased fluids have a purchase and disposal cost of $12 per gallon. In the event of a spill, no additional costs should be accrued since the material is biodegradable. Other costs may be associated depending on the size and location of the spill; however, these spill-related costs should still be less than those associated with petroleum-based fluids.

Suggested Implementation Applications

The following general purpose and tactical equipment currently use petroleum-based and synthetic fluids: Bradley Fighting Vehicle, M1A2 Abrams Main Battle Tank, Carrier Ammunition Carrier Command Post, Carrier Multiple Launch Rocket, Carrier Mortar 107mm, Carrier Personnel M113A2, Carrier Smoke Generator, Combat Vehicle ITV-M901A1, Infantry Fighting Vehicles, Landing Craft Mechanized LCM8, Landing Craft Utility, Lighter Air Cushion Vehicle 30-ton, Tank Combat Full Tracked, Armored Combat Earthmover ACE M9, Armored Recon ABN Assault Vehicle, Bridge Launcher Armored Vehicle, Carrier Ammunition, Crane Shovel 20-ton, Hammer Pile Drivers, and Howitzers.

Points of Contact

- Linwood Gilman, DSCR, (804) 279-3518, linwood.gilman@dscr.dla.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- George Handy, NDCEE, (803) 641-0203, handyg@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Can-Am COATAIR Turbine-Heated Air High-Volume Low-Pressure System

Based on its extensive technical expertise with coating technologies, the NDCEE was tasked to evaluate the Can-Am COATAIR Turbine-Heated Air High-Volume Low-Pressure (HVLP) System as an alternative to the compressed air HLVP application system currently used in aircraft coating applications.

Technology Description

The system contains an HVLP electric motor air turbine that delivers a large volume of warm air at a constant pressure directly to the spray gun. The warm air is produced by the mechanical action of the electric turbine motor. Because the spray gun constantly bleeds turbine-produced air, no sudden expansion of the air comes out of the spray gun as with conventional air or high-pressure systems. The turbine, running at high speed, compresses the air through a restricted orifice and then allows the air to expand naturally. Through each stage of the turbine, the temperature increases, until it leaves the turbine at temperatures of 130–190°F above ambient. The hot air warms the spray gun and, in turn, the paint with air that is free from moisture, condensation and compressor-lubricating oil. The hot air thins the paint to a more suitable viscosity. The hot air speeds evaporation of reducing solvents, making the solvent flash more rapidly because the paint is warm. The hot air also reduces blush from fast dry lacquer on days with high relative humidity.

The HVLP industrial quality spray gun has a fluid and atomizing air adjustment at the rear of the spray gun. The spray pattern fan size can be adjusted 1–20 inches. Paint can be applied at a rate of 1700 cubic centimeters per minute. Low air pressure reduces paint spray bounce back. The spray gun has a high transfer efficiency that ensures that VOC emissions are minimized. The atomized paint gently floats from the spray gun to the part. Paint does not bounce back or swirl around the target in a cloud.

For the NDCEE demonstration, a Can-Am COATAIR Turbine-Heated Air HVLP with remote pressure feed cup was used. The model 2100H-2HC applicator outfitted with a hardened SS “C” air cap (medium/large fan, part #9062), a “C” fluid tip (1.0 mm diameter, part #9272) and a “C” fluid needle (1.0 mm diameter, part #9282) was mounted on a Can-Am series 2020 gun body. The system was demonstrated using a compressed air pressure of 6.5 pounds per square inch @ gauge. The system provided a typical fan pattern similar to the standard HVLP application (10-inch width at a 12-inch distance).

The applicator was configured in reverse to conventional compressed air HVLP applicators by feeding paint flow up through the handle of the applicator and introducing atomization air near the spray nozzle. This configuration allows the fluid to be pressurized and heated at the spray nozzle of the applicator. The fluid is heated to 135°F at a rate of up to 250 milliliter per minute. The turbine-heated air energy is transferred to the coating via both convection and conduction. The 5-horsepower floor-mount turbine can provide up to 200 standard cubic feet per minute supplying 4–6 guns at 6.0–9.5 pounds per square inch atomization pressure.

Technology Benefits and Advantages

- Improved transfer efficiencies
- Consistent film thickness in the primer and final topcoat application
- Smooth coating appearance
- Quality of finish and the consistency of spray quality may provide long-term economic benefits in reduced coating consumption and quality rejections

DoD Need

Environmentally preferred coating application system

Army: CM-3, P2-1

Air Force: 1232

Navy: 2.I.01.g, 3.I.04.h

Technology Limitations

- High initial investment costs
- Additional operational and maintenance training requirements
- Proper thermal insulation of static components and coverage of dynamic components are needed to limit seasonal effects on outdoor use, especially for aircraft coating

NDCEE FY01 & FY02 Accomplishments

- Produced a Recommendations Report (FY01) that identified two coating application equipment systems that potentially could achieve improved atomization and improved transfer efficiency compared to a baseline HVLP application system while obtaining acceptable coating application performance. The selected coating application systems were the Can-Am COATAIR Turbine-Heated Air HVLP system and the Linden/Nordson SuperCritical Carbon Dioxide ($SCCO_2$) system.
- Conducted demonstrations of the Can-Am COATAIR Turbine-Heated Air HVLP system and a $SCCO_2$ system at the NDCEE Demonstration Facility (FY01).
- Produced a Coatings Application Equipment Evaluation Final Report (FY02) that documented the results of the demonstrations and provided financial analyses based on the ECAM[SM] tool. Demonstration results showed that the Can-Am HLVP system had an average transfer efficiency improvement of 7% above the baseline HLVP (1.4% higher for the primer and 14.0% higher for the topcoat). However, based on the economic analysis, the NDCEE recommended that no further validation and qualification work for the Can-Am HVLP application system should be performed (unless a high-priority DoD need materializes that requires further attempts to optimize this technology).

Economic Analysis

ECAM[SM] results showed that the Can-Am HVLP application equipment is slightly more cost effective to operate than the current painting process on an annual basis. The initial investment cost of the Can-Am system is approximately $104,500. This investment cost is based on the cost of the site preparation, equipment costs, and one-time new equipment training requirements for implementing the proposed alternative painting application processes. The 15-year internal rate of return is approximately 17% and the payback period is nearly 7 years.

Suggested Implementation Applications

None

Points of Contact

- Michael Wrazen, Industrial Ecology Center, (973) 724-3730, mwrazen@pica.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Scott Sager, NDCEE, (814) 269-6457, sager@ctcgsc.org

Applicable NDCEE Task

Coatings Application Equipment Evaluation (Task N.000-01, Subtask 3)

Electronic Equipment Demanufacturing Recycling and Reuse System

The NDCEE is demonstrating and validating improved processes and technologies for the demanufacturing of electronic equipment. As part of its contributions, the NDCEE is revitalizing standards, procedures and facility and equipment design associated with fostering a total life-cycle approach to managing electronic equipment.

Technology Description

The Electronic Equipment Demanufacturing Recycling and Reuse System is an integrated system of eight (8) modules that processes electronic equipment into reusable or recyclable components. Typical equipment includes computers, radar devices and communication devices. The modules are:

1. Receiving/Storage/Shipping—controls and accounts for each retired electronic equipment as it flows into and out of the demanufacturing facility. Material tracking and accounting has become an important aspect of DoD modernization efforts to reduce costs, avoid waste and minimize pollution.
2. Handling—controls the movement of material within the demanufacturing facility.
3. Disassembly—dismantles electronic equipment into more basic subassemblies or components that can be either recovered for reuse or further processed for materials recovery. Although disassembly can be performed using basic hand tools, more sophisticated disassembly techniques may be incorporated into the disassembly process to reduce labor costs.
4. Component Recovery—efficiently identifies and recovers critical components for reuse. Recovered components can be used to maintain the operational readiness of aging DoD systems that are plagued by parts shortages.
5. Testing—identifies equipment, subassemblies and components that have reuse potential or may have marketable value in the commercial marketplace.
6. Glass Recovery—separates unleaded from leaded cathode ray tube (CRT) glass and then prepares the CRT glass for reuse. Processed CRT glass is in the form of recyclable cullet, which can be used by CRT glass manufacturing facilities.
7. Metals Recovery—uses a more cost-effective and environmentally friendly process to separate metals and nonmetal materials from printed wiring boards. The process yields improved precious metal recovery at a lower processing cost to increase revenue.
8. Plastics Recovery—uses a novel processing system wherein engineering plastics are separated into high-purity concentrations of compatible types, suitable as replacement for raw material. This process obtains the greatest possible value from the material, increasing revenues and minimizing a waste stream.

Technology Benefits and Advantages

- Reduces solid waste generation
- Accomplishes demilitarization while recovering valuable electronic parts needed to maintain DoD systems
- Removes hazardous components for proper disposal to avoid present and future liability
- Returns revenue to the military services

DoD Need

Reuse/recycle electronic materials

Navy: 3.I.13.a

Typical electronic equipment includes computers, radar devices and communication devices.

Technology Limitations

- System is still undergoing testing and has not been made commercially available.
- Facilities require appropriate pollution controls or regulatory permits.
- Output will be dependent on the composition of the input stream of retired electronic equipment.

NDCEE FY01 & FY02 Accomplishments

- Held annual stakeholder meetings and information exchanges, including the Federal Electronics Stewardship Workshop that focused on federal agency electronic assets management (FY00, FY01 and FY02).
- Gathered data at approximately 60 demanufacturing and recycling facilities to review DoD and industry practices (FY00 and FY01).
- Completed a facility modification and build-out (FY01).
- Prepared approximately 40 technical reports and 8 Technical Data Packages/ Operations & Maintenance Manuals (FY01 and FY02).
- Designed, procured and installed a demonstration/validation capability for each of the eight modules in the NDCEE Demanufacturing Technology Facility (FY02).
- Completed initial demonstration/validation activities on each of the 8 modules of the demanufacturing process (FY02).
- Conducted a cost-benefit analysis to develop a validation site recommendation for a pilot system (FY02).
- Conducted a needs assessment to determine DoD's highest priority electronic waste streams (FY02).
- Installed and began validating the performance of a pilot system to cost-effectively recycle two high-priority DoD waste streams (FY02).
- Maintaining the Demanufacturing of Electronic Equipment for Reuse and Recycling (DEER2) Web site (www.deer2.com), which is a repository of the most comprehensive compilation of electronics demanufacturing information currently available (ongoing).

Economic Analysis

The Defense Reutilization and Marketing Service is responsible for disposing of more than 30 million pounds of DoD electronic equipment annually. After examining DRMS practices and DRMS contractors, the NDCEE estimated that improved DEER2 methodologies and technologies have the potential to return $1 million per year to the Government in material recycling and component recovery fees. In addition, demanufacturing scrap electronic equipment can save approximately $400,000 in demilitarization annually. Finally, DoD can avoid approximately $25 million annually in third-party site cleanups if electronic scrap disposal is properly managed. The reuse of components and systems that could be returned to the military or to commercial use is an additional savings that could be significant, but has not been quantified.

Suggested Implementation Applications

The Electronic Equipment Demanufacturing Recycling and Reuse System was designed for demanufacturing facilities to process electronic equipment into reusable or recyclable components.

Points of Contact

- Robert Moreira, U.S. Army Industrial Ecology Center, (973) 724-2617, rmoreira@pica.army.mil
- Darlene Bader-Lohn, ODASA(ESOH), ACOR, (410) 436-6861, darlene.bader-lohn@aec.apgea.army.mil
- John Barrett, Defense Reutilization and Marketing Service, (616) 961-5946, jbarrett@mail.drms.dla.mil
- Edward Wegman, NDCEE, (727) 549-7035, wegmane@ctcgsc.org

Applicable NDCEE Tasks

Demanufacturing of Electronic Equipment for Reuse and Recycling (Tasks N.228 and N.302)
Pilot Electronic Equipment Demanufacturing and Recycling Validation System (Task N.251)

ElectroSpark Deposition Micro-Welding Process

The NDCEE has demonstrated and evaluated the feasibility of using the ElectroSpark Deposition (ESD) process to replace electroplated hard chromium (EHC). The NDCEE has determined that ESD offers life-cycle performance and costs that are comparable to or better than EHC.

Technology Description

Chromium electroplating is one of the most widely used surface treatment processes throughout the military services and represents significant contributions to hazardous waste generation and pollution control costs. Alternative technologies are required that will reduce or eliminate the dependence on this process while providing equal or superior performance in wear and corrosion protection. The High-Velocity Oxy-Fuel (HVOF) process is an alternative technology that is gradually replacing chrome electroplating in some applications. Other alternatives are required for applications where HVOF coatings cannot be applied because of geometry constraints or because of service conditions exceeding the damage resistance of the HVOF coating.

In recent years, a coating technology has been developed that can produce robust, damage-resistant coatings. In contrast to most coatings that may produce chemical or mechanical bonds with a substrate, the ESD process creates a true metallurgical bond while maintaining the substrate at or near ambient temperatures. Research is in progress to develop ESD to coat non-line-of-sight applications and configurations, which include angles, crevices and small inner diameters or insides of blind holes. This technique is potentially the next evolution in the process that will offer significant benefits over the currently available technology and one that will complement the existing HVOF alternative by coating geometries that are not possible using HVOF.

The ESD technology is a micro-welding process that uses very short duration, high-current electrical pulses to deposit electrode material on a metallic substrate. An ESD system is comprised of a capacitor-based power supply and an electrode holder (or applicator). Its function is to deposit a consumable electrode onto the substrate by means of electric sparks. When the capacitor energy is released, the direct current generates a plasma arc between the tip of the electrode and the substrate. At temperatures between 8,000–25,000°C, the plasma arc ionizes the consumable electrode and a small quantity of the electrode material is transferred onto the work piece. The period of the high-energy pulse is extremely short relative to the interval period, so very little heat is transferred or accumulated to the substrate during each cycle. The low heat input to the substrate results in little or no heat-affected zone, distortion, pitting, shrinkage or internal stress.

Technology Benefits and Advantages

- Achieves surface builds and coating hardness and smoothness that are comparable to EHC used in non-line-of-sight applications
- Possesses fewer inherent environmental and worker safety risks than hard chromium electroplating
- Provides life-cycle performance and costs (including component rework and repair requirements) that are comparable to or better than EHC
- Provides wear performance that is similar to or better than EHC
- Maintains or improves production rate and/or part quality while minimizing maintenance requirements

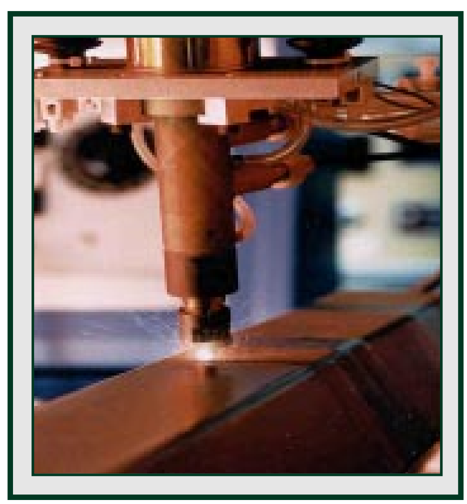
DoD Need

Alternative non-chromium plating method

Army: P2-6

Air Force: 613

Navy: 3.I.03.e



Electrospark Deposition Process

Technology Limitations

- Technology limitations will be determined from Pacific Northwest National Laboratory's (Richland, Washington) demonstration of the ESD process and NDCEE screening testing.

NDCEE FY01 & FY02 Accomplishments

- Identified 4340 steel substrate as the substrate for deposition and selected coating materials (FY01).
- Developed a Screening Test Plan to evaluate ESD coatings on the 4340 steel substrate for corrosion resistance, wear resistance and fatigue (FY01).
- Conducted corrosion resistance and wear resistance screen testing (FY02). A screen testing report will be prepared and submitted in FY03.

Economic Analysis

EHC represents a significant contribution to hazardous, carcinogenic waste generation and pollution control costs. Increasingly stringent OSHA and EPA regulations will continue to increase costs of hexavalent chromium processes. ESD shows cost-effective potential because substrates require no special surface preparation, and the process releases no hazardous wastes, fumes or effluents and requires no special chambers, spray booths or operator protection.

Suggested Implementation Applications

DoD repair facilities that use hard chromium processes would benefit from ESD. The equipment is portable and can be used in repair depots, shop, field and shipboard as well as at original equipment manufacturer plants.

Points of Contact

- Andrew Goetz, Industrial Ecology Center, (973) 724-6324, agoetz@pica.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Scott Sager, NDCEE, (814) 269-6457, sager@ctcgsc.org

Applicable NDCEE Tasks

Surface Treatments for Enhanced Wear Resistance (Task N.245)
ElectroSpark Deposited Coatings for Replacement of Chrome Electroplating (Task N.253)

Fiber Media Blasting

Under previous efforts, the NDCEE and Naval Surface Warfare Center, Carderock Division tested several alternatives, including fiber media blasting, to current coatings removal and etching methods at the NDCEE Demonstration Facility. The NDCEE utilized these efforts to help identify potential alternatives to chemical or mechanical coatings removal processes for use on delicate substrates, many of which are also dimensionally critical parts. Fiber media blasting was found to be a technically and economically viable alternative for removing nonskid coatings from special hull treatment (SHT) tiles on LOS ANGELES (SSN 688) Class submarines.

Technology Description

Fiber media blasting offers a seamless method of surface preparation, cleaning and decontamination of substrates. The media is a fiber-reinforced polymer matrix that is a composite of fiber, resin, polymer and the desired surface treatment particles (plastic, cellulose, walnut, steel, or aluminum oxide). On average, this technology has a throughput of 400–600 pounds of media per hour and consumes 50–70 pounds of media per hour.

Three common types of fiber media are cleaning fiber medium, walnut fiber medium, and aluminum oxide fiber medium 30. The cleaning fiber medium consists of a no-profile, nonabrasive, cleaning medium. It is used for soft substrate cleaning, grease, and oil removal. It contains no abrasive content and is safe for rubber and plastic surfaces. The walnut fiber medium is also a no-profile-cleaning medium but uses walnut shells for low-abrasive cleaning. This type of medium is typically used for coatings removal on sensitive substrates and equipment and is effective in cleaning harder surface contaminants. The aluminum oxide fiber medium 30 is the most aggressive medium available with a 3-plus mil profile. This medium is used for industrial coatings removal and decontamination.

The NDCEE has demonstrated an engineered media blaster that includes a media vibrator to ensure even flow rates through a wide range of media types, an air muffler for quieter depressurization, a pneumatic media flow valve for maximum control, a large manhole cover for easy clean out, and a large pop-up valve and inlet for fast charging. Other systems available for use with the media blaster are a vapor injection system and media classifier. The vapor injection system introduces pressurized vapor into the blast air stream to accelerate surface treatment operations, combine multiple surface preparations into one process, and dramatically reduce dust generation. Using a classifier, the media can be recycled anywhere from 5–15 times. The amount of times the media can be recycled depends on the type of surface and contaminants being removed. Some features of the classifier include a waste screen that separates large debris and contaminants from the media, another screen to remove dust and consumed abrasives from reusable media, a rotational system to ensure an exact flow pattern to maximize production and a motor access panel for easy maintenance.

Technology Benefits and Advantages

- Eliminates hazardous airborne particulates from blasting operations, decreases solid waste, and eliminates the use of chemical strippers
- Reduces labor and operating costs as a result of decreased pre-removal preparation and post-removal cleanup
- Improves safety and worker health conditions due to the elimination of airborne emissions of heavy metals and other contaminants when used with vacuum recovery
- Is recyclable media

DoD Need

Environmentally preferred coatings removal technique

Army: CM-3, P2-1

Navy: 2.I.01.g, 3.I.05.a

Air Force: 225, 311, 814, 988, 1232, 1468

- Helps facilities comply with Executive Order 13148, which requires DoD to decrease the amount of waste generated at federal facilities, as well as environmental regulations regarding airborne particulate emissions

Technology Limitations

- Not as aggressive on metallic substrates as some, more abrasive media. However, unlike fiber media, abrasive media do not have the capability to be used on delicate substrates.

NDCEE FY02 Accomplishments

- Produced an Alternatives Report that identified the needs and requirements for alternative coatings removal technologies from delicate substrates (FY02). Fiber media blasting was recommended for evaluation on hoods from High-Mobility Multipurpose Wheeled Vehicles (HMMWVs), SHT and passive countermeasure system (PCMS) tiles, and U.S. Navy and Air Force radomes.
- Produced a Demonstration Report that summarized key results used to assess alternative coatings removal technologies and compared their performance to the baseline removal methods. The alternative process was demonstrated at Norfolk Naval Shipyard and Naval Station Mayport. The fiber media blasting technology removed nonskid coatings from SHT at an average rate of 28 square feet per hour.
- A cost analysis was completed using the ECAM℠ tool to ensure environmental, safety and health issues associated with these processes were included. The results of this ECAM℠ were summarized in a Justification Report (FY02). The fiber media technology was recommended for implementation to remove nonskid coatings from the steel submarine hull.

Economic Analysis

The NDCEE conducted a cost-benefit analysis in which it compared fiber media blasting to current removal methods for nonskid removal from SHT tiles. Capital costs for the fiber media blasting equipment are approximately $44,500. Annual operating costs are estimated to be $13,779. The operating costs for the dry abrasive blasting equipment is estimated to be $63,247. Pearl Harbor Naval Shipyard supplied the baseline data.

Based on ECAM℠ results, the simple and discounted payback periods for the fiber media technology are less than one year. The NPV for each study period (5, 10, and 15 years) is positive ranging approximately $200,000–$600,000. The IRR values of 120–122% are acceptable to justify the investment.

Suggested Implementation Applications

Fiber media blasting may be used on a variety of delicate substrates. Applicable weapons system components include SHT tiles on submarines, fiberglass hoods on HMMWV, and potentially Navy and Air Force radomes.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org
- Georgette Kotsagrelos, NDCEE, (412) 577-2655, kotsagre@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

FLASHJET® System

The NDCEE evaluated the applicability of the FLASHJET® process for use by Corpus Christi Army Depot on flight-critical status helicopter rotor blades. Under previous efforts, the NDCEE has tested FLASHJET® systems for the removal of coatings from submarines and surface ships. The system proved effective at removing coatings from special hull treatment tiles, without damaging substrate materials.

Technology Description

The FLASHJET® system is a pulsed optical energy decoating process that was developed by McDonnell Douglas Aerospace, now the Boeing Company, to remove coatings from aircraft. The process has since been sold to Flash Tech, Inc.

A fully automated process, the FLASHJET® system uses carbon dioxide (CO_2) pellet blasting combine with a Xenon flash lamp to remove coatings. The flashlamp generates high-energy pulses powerful enough to break the molecular bonds of the coating. The coating is reduced to a fine ash. This "ablative" process is immediately followed by a CO_2 pellet flush to clean and cool the surface. Upon impact with the painted surface, the pellets cause a large temperature difference between the coating and the substrate. This temperature differential weakens the bond between any remaining coating and the substrate. The CO_2 pellets sublimate on impact. The CO_2 rapidly expands during this sublimation, resulting in a high-velocity stream that overcomes the weakened bond between the coating and the substrate and removes the ash and any remaining coating. The CO_2 is released as a gas, leaving only the removed paint and other contaminants removed from the part as waste.

The FLASHJET® system has been shown to remove up to 4 square feet of coating per minute. The removal rate is dependent on the coating system and corresponding thickness of the coating being removed. It requires little or no pre-clean or masking prior to stripping. Once the coating has been removed, the cleaned surface is ready to paint with no additional surface preparation. However, as a line-of-sight process, the system may have difficulty removing coatings from sharp radius corners and shadowed areas.

Robot gantry systems have been developed to automate the FLASHJET® process and have reduced the labor requirement in some applications to one operator. This operator programs the equipment, controls the set-up, inspects the surface after processing, and manages the control room.

DoD Need

Environmentally preferred coatings removal technique

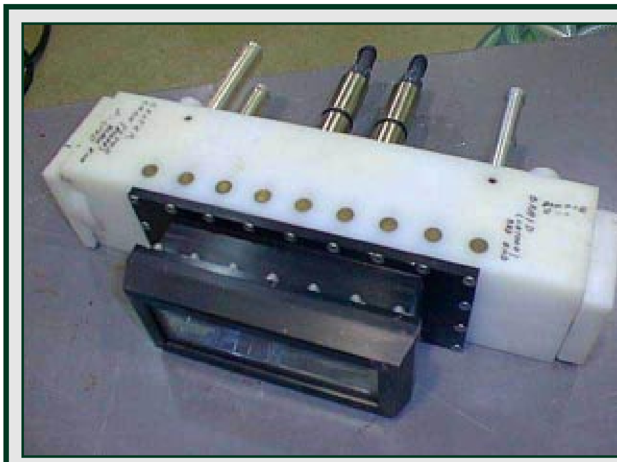
Army: CM-3, CM-4, CM-9, P2-6

Navy: 2.I.01.g, 3.I.05.a

Air Force: 225, 311, 814, 988, 1232, 1468

Technology Benefits and Advantages

- Reduces operator fatigue and increases operator safety through robotics
- Eliminates hazardous airborne particulate from blasting operations, decreases solid waste and eliminates the use of chemical strippers
- Reduces labor and operating costs as a result of decreased pre-removal preparation and post-removal cleanup
- Improved safety and worker health conditions due to the reduction of airborne emissions of heavy metals and other contaminants
- Helps facilities comply with Executive Order 13148, which requires DoD to decrease the amount of waste generated at federal facilities, as well as environmental regulations regarding airborne particulate emissions



The FLASHJET®'s Xenon flashlamp generates high-energy pulses powerful enough to ablate the coating from an aircraft exterior or component.

Technology Limitations

- Produces CO_2 gas, which requires ventilation since CO_2 is an asphyxiant
- Has line-of-sight limitations

NDCEE FY02 Accomplishments

- Produced an Alternatives Report that identified the needs and requirements for alternative coatings removal technologies from delicate substrates (FY02). The FLASHJET® System was recommended for evaluation on helicopter rotor blades.
- Produced a Demonstration Report that summarized key results used to assess alternative coatings removal technologies and compared their performance to the baseline removal methods (FY02). This alternative process was demonstrated at Corpus Christi Army Depot. The FLASHJET® technology removed a polyurethane topcoat (MIL-C-46168) and epoxy primer (MIL-P-23377) system from helicopter rotor blades (honeycomb structures) from the Apache and the Blackhawk. Its approximate removal rate was 270 square feet per hour, which is 15 times faster than the average baseline rate of manual hand sanding.
- Completed a cost analysis using the ECAM℠ tool to ensure environmental, safety and health issues associated with these processes were included. The results of the ECAM℠ are summarized in a Justification Report (FY02).

Economic Analysis

The NDCEE conducted a cost-benefit analysis that compared FLASHJET® to hand sanding (baseline) for use on helicopter rotor blades. Capital costs for the FLASHJET® equipment are approximately $2.9 million. Annual operating costs are estimated to be $85,735. The operating costs for the dry abrasive blasting equipment is estimated to be $530,159. CCAD supplied the baseline data. Simple and discounted payback periods of 6.5 and 7.5 years, respectively, were achieved. The 15-year NPV is projected to be $2.3 million; the IRR is 13%.

In the case of CCAD, the FLASHJET® process had previously been implemented on site to strip various helicopter airframes. The technology was approved for use on these nonflight components, but not on flight-critical rotor blades. By utilizing the technology on rotor blades, CCAD would incur no additional capital investment and its cost savings would be approximately $450,000 per year.

A reasonable conclusion is that lower payback periods would be achieved by increasing the workload of the FLASHJET® system. This increase could be accomplished by increasing the number of blades processed or including a second component, such as the helicopter airframes. Note that the values for CCAD do not include the airframes that it currently strips with the FLASHJET® system.

Suggested Implementation Applications

Through a Strategic Environmental Research and Development Program effort, the FLASHJET® technology was validated by conducting panel testing using metallic and composite substrates for the Air Force and Navy. The Navy approved the use of FLASHJET® on metallic fixed-wing aircraft in 1997. The FLASHJET® system is currently used for fuselage coatings removal on F-15 Eagle, C-130 Hercules, C-141 Starlifter, C-5 Galaxy, and P-3C Orion aircraft as well as Chinook (CH-47D), Apache (AH-64), Blackhawk (UH-60), Cobra (AH-1), Huey (UH-1), Seahawk (SH-60), and Kiowa (OH-58) helicopters.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org
- Georgette Kotsagrelos, NDCEE, (412) 557-2655, kotsagre@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Flow-Measuring Devices

The NDCEE assisted Puget Sound Naval Shipyard with selecting and purchasing flow-measuring devices (FMDs) for the process water collection system (PWCS). The FMDs will help to accurately measure process water being discharged.

Technology Description

FMDs are used to monitor the flow of storm water and industrial wastewater, collectively referred to as process water, and aid in determining contaminant levels, thereby ensuring compliance to a facility's National Pollutant Discharge Elimination System (NPDES) permit requirements. For example, at PSNS, the process water collects on six drydock floors and drains to a sump. Normally, the collected process water is discharged to Sinclair Inlet; however, if the contaminant levels exceed PSNS's NPDES permit limits, the process water is discharged to the sanitary sewer system. The FMDs monitor the discharge from the PWCS and determine the quantities that enter the pristine inlet and/or the sewer system. Some of the flow meters require special housings for submerged application in salt water.

Flowmeter technology has expanded greatly in the last 2–3 decades. In addition to the typical technologies, such as turbines and differential pressure (DP), FMDs that measure flow using the physical principles of the coriolis effect, electromagnetism and sonic wave reflection are now available. Each technology has applications for which it is most suitable. For instance, turbine and thermal technology are suitable for clean process water and gases, but not for naval drydock process water that is inherently dirty, containing pollutants and solids.

The following list and table describe various types of FMDs that were considered for the PSNS application.

Coriolis: This technology provides a direct mass flow measurement based on the principle of the Coriolis effect or conservation of angular momentum due to the Coriolis acceleration of a fluid stream. This technology provides accurate results and can be used for dirty liquids on a limited basis. However, it is extremely costly at the 4-inch and 6-inch sizes. It is typically twice as expensive as the magnetic-type flowmeters and is generally not available larger than 4-inch pipe size.

Differential Pressure: DP is a less expensive, older technology that measures flow based on the principle of conservation of energy between the liquid static and velocity head. Types of DP flowmeters include orifice, nozzle, flow venturi and pitot tube. One of the advantages of this technology is its consistency and common usage. However, its disadvantage is the permanent pressure loss due to pipe constriction at the measurement point and potential for fouling. This type of flowmeter requires regular maintenance to prevent fouling at the constriction point.

Magnetic: This technology uses the principle of electromagnetism to measure flow through the meter spool. This meter is commonly used in dirty water applications, such as those at wastewater treatment plants, since no obstructions are inside the meter spool, thus eliminating fouling problems.

Transit-Time Ultrasonic (TTU): TTU technology uses sound wave travel time from one side of the pipe to the other to calculate flow rate. The travel time is proportional to flow rate. One of the benefits of this technology is that it is nonintrusive; it is clamped to the outside of the pipe. TTU flowmeters are mainly used for clean liquids such as potable water systems.

DoD Need

Improved monitoring of process water discharges

Army: CM-10

Navy: 2.II.02.b

Doppler Ultrasonic (DU): DU uses the same principles as TTU but can be used for dirty fluid service. It requires a certain amount of particles and bubbles in the service liquid for optimum reading, which may vary depending on the process fluid. It is typically 40–50% more expensive than magnetic-type flowmeters at the 4–6-inch pipe size.

Technology Benefits, Advantages and Limitations

The following table presents the existing FMD technologies, pipe size ranges, advantages, disadvantages and suitability for dirty water service. Drydock process water is considered dirty water, which is addressed by the last column.

Flowmeter Drydock Process Water Application Table

Flowmeter Type	Pipe size	Advantages	Disadvantages	Suitability for Dirty Fluid Service
Coriolis	1/6 to 6 in.	High accuracy; low maintenance; insensitive to flow profile	High initial cost, depending on size and model; bent tubes subject to fouling; not available for pipe sizes over six inches	Limited
Differential Pressure	1/2 in. and up	Low initial cost; ease of installation; well understood; many industry approvals	Limited range; permanent pressure drop; uses square root method to calculate flowrate; requires periodic maintenance	Limited
Magnetic	1/10 to 100 in.	Obstructionless; high accuracy; no pressure drop	Cannot meter nonconductive fluids (e.g., hydrocarbons); relatively high initial cost; electrodes subject to coating	Yes
Transit-Time Ultrasonic	1/2 in. and up	High accuracy, depending on model; obstructionless; clamp-on convenience; no pressure drop	Limited ability to handle dirty fluids; can be affected by flow profile; some models have high initial cost	Limited
Doppler Ultrasonic	1/2 in. and up	Can meter dirty flows; no pressure drop; clamp-on convenience	Low-to-medium accuracy; Reynolds number limitations	Yes

Note: Table was derived from Table II and Table III in Jessie Yoder, "Flowmeter Shootout Part III: How Users Choose," *Control Magazine*, March 9, 2001.

NDCEE FY01 & FY02 Accomplishments

- Based on a needs assessment conducted for PSNS by the NDCEE in FY01, the NDCEE recommended magnetic flow tube (or spool) FMDs for installation at PSNS based on the devices' ruggedness, higher accuracy, higher reliability, low maintenance and low cost (by approximately 30–50%) relative to other flow meters. Magnetic FMDs also have more common industry usage in dirty water applications.
- The NDCEE prepared a bid package for magnetic flow tube FMDs. The bid package was sent to six vendors in FY02.
- Based on a review of the bids, the NDCEE decided to obtain the Promag 50W Series Remote Version Electromagnetic Flow Meter. The NDCEE purchased five 6-inch and six 4-inch magnetic flow tube FMDs, and transferred them to PSNS for installation in the PWCS in FY02.

Economic Analysis

By considering system ruggedness, reliability and maintenance requirements along with purchase price, a near life-cycle cost approach was taken in the evaluation of available FMDs on behalf of PSNS. Magnetic flowmeters proved to be the most economical long-term metering solution for this application. Five 6-inch and six 4-inch electromagnetic flow meters with associated displays, cables and data loggers were purchased for under $21,000.

Suggested Implementation Applications

Any site with an NDPES permit should have an FMD. Sites with dirty fluid flow, should consider magnetic flowmeters. Because these FMDs do not have any moving parts or obstructions in the flow zone, they are ideal for measuring dirty fluid flow. Their reasonable cost combined with high reliability and low maintenance make them valuable in remote or hard-to-access locations, such as the pump wells of shipyard drydocks.

Navy submarine in drydock

Points of Contact

- Robert Nestor, Industrial Ecology Center, (973) 724-2200, rnestor@pica.army.mil
- Allan Butler, NDCEE, (360) 782-5554, butler@ctcgsc.org

Applicable NDCEE Task

Puget Sound Naval Shipyard Pollution Prevention Equipment and Services (Task N.217)

Fuel Cells

The NDCEE is providing fuel cell assistance to the U.S. Army Engineer Research Development Center/Construction Engineering Research Laboratory, which was assigned the mission of managing the Fuel Cell Demonstration Program for the DoD. The technical assistance is in the form of providing evaluations and recommendations relative to performance, emissions, reliability, operability, maintainability, and overall life-cycle costs of power plant systems and subsystem components. During FY99–FY00, the NDCEE designed and constructed the DoD Fuel Cell Test and Evaluation Center (FC*Tec*), Johnstown, Pennsylvania. The FC*Tec* mission is to significantly accelerate the development and commercialization of fuel cell power systems for military and commercial applications. The NDCEE also installed a 200-kilowatt (kW) PC25C Phosphoric Acid Fuel Cell Power Plant with customized capabilities, an AVISTA SR-12 modular proton exchange membrane generator, and testing equipment in the FC*Tec*.

Technology Description

Fuel cells generate electricity through an electrochemical process in which the energy stored in a fuel is converted directly into direct current (DC) electricity. Because electrical energy is generated without combusting fuel, fuel cells are extremely attractive from an environmental standpoint due to their low emissions and other factors. They can be used as stand-alone power sources for off-grid, remote sites or as a backup power source to an on-grid site. Thermal output from the fuel cell can be used for heating boiler makeup water, space heating, condensate return, process hot water, etc.

DoD Need

Use of alternative or renewable energy sources to help facilities comply with the U.S. Energy Policy Act of 1992 and other federal, state and military directives

Army: P2-8

Navy: 2.I.01.b, 2.I.01.i

All fuel cells have the same basic operating principle. A fuel cell is a device that converts the energy of a fuel [hydrogen (H_2), natural gas, methanol, gasoline, etc.] and an oxidant (air or oxygen) into useable electricity. Fuel cell construction generally consists of a fuel electrode (anode) and an oxidant electrode (cathode) separated by an ion conducting membrane. The input fuel passes over the anode (and oxygen over the cathode) where it splits into ions and electrons. The electrons pass through an external circuit to serve an electric load while the ions move through the electrolyte toward the oppositely charged electrode. At the electrode, ions combine to create by-products, primarily water and carbon dioxide. Depending on the input fuel and electrolyte, different chemical reactions will occur.

The four primary types of fuel cells (their names correspond to the electrolyte employed) are phosphoric acid, molten carbonate, solid oxide, and proton exchange membrane. A comparison of the fuel cell types is summarized in the table (below).

Fuel cells are typically grouped into three sections: fuel processor, power section and power conditioner. In the fuel processor, a fuel, such as natural gas, is reformed to

Feature Comparisons Among Fuel Cell Applications

	Phosphoric Acid	Molten Carbonate	Solid Oxide	Proton Exchange Membrane
Electrolyte	Phosphoric Acid	Molten Carbonate Salt	Ceramic	Polymer
Operating Temperature	375°F (190°C)	1200°F (650°C)	1830°F (1000°C)	175°F (80°C)
Fuels	H_2 Reformate	H_2/CO/ Reformate	$H_2/CO_2/CH_4$ Reformate	H_2 Reformate
Reforming	External	External/Internal	External/Internal	External
Oxidant	O_2/Air	CO_2/O_2/Air	O_2/Air	O_2/Air
Efficiency (HHV)	40–50%	50–60%	45–55%	40–50%

chemically extract the hydrogen atom from the host fuel. The hydrogen-rich fuel and oxygen (air) then feeds into the power section to produce DC electricity and reusable heat. This section includes a fuel cell stack, which is a series of electrode plates interconnected to produce a set quantity of electrical power. The output DC electricity is converted to alternating current electricity in the power conditioner.

Technology Benefits and Advantages

- Use of alternative or renewable energy sources helps facilities comply with the U.S. Energy Policy Act of 1992 and other federal, state and military directives
- Improves energy conservation and reduces environmental impacts in comparison to traditional energy sources
- High-energy conversion efficiency, fuel flexibility and cogeneration capability
- Modular design
- Very low chemical and acoustical pollution
- Rapid load response

Technology Limitations

- Initial equipment costs may be high, but are improving as the technology becomes more widely disseminated.
- As with any new and advanced power technology, fuel cells involve design and construction planning as well as additional maintenance training.
- Distributed power sources require dedicated onsite space requirements.
- Caution must be exercised since high voltages are a potential danger.

Economic Analysis

For United Technologies Company 200-kW PC25C, the NDCEE determined that the average cost for a typical installation excluding any geographic cost index adjustments for labor should be in the $90,000–$100,000 range. Any nontypical or auxiliary equipment will be in addition to the base installation cost. The installation costs for some of the military fleet have been recorded and tabulated to allow review of installation options, interface requirements, and installation cost. These initial fuel cell systems cost an average of $110,000, with a minimum cost of $84,000 and a maximum cost of $200,000.

Fan Skid

NDCEE FY01 & FY02 Accomplishments

- Providing support to ERDC/CERL test programs to enhance the performance of the fuel cell systems as well develop standardized test and validation processes for use by other organizations considering the application of fuel cells (FY01–FY03)
- Purchased and installed a 5-kiloWatt combined heat and power proton exchange membrane fuel cell system (FY02)

Suggested Implementation Applications

Fuel cells may be used by any site that requires a power source and are particularly useful for remote, off-grid sites. The DoD Fuel Cell Demonstration Program sites represent a broad spectrum of facilities and locations throughout the major Services.

High-Power Thermal Load Bank

Points of Contact

- Dr. Michael Binder, CERL, (217) 373-7214, m-binder@cecer.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Scott Kenner, NDCEE, (814) 269-2891, kenners@ctcgsc.org

Applicable NDCEE Task

U.S. Army ERDC/CERL Fuel Cell Technology Program (Task N.211)

Ion Implantation Process

The NDCEE has demonstrated and evaluated the feasibility of using ion implantation systems to deposit various metals on Inconel 718 and 4340 steel substrates. The NDCEE has determined that the process is a viable enhancement of EHC and can be used to extend the service life of the original component (with or without EHC).

Technology Description

Ion implantation is a surface modification process in which ions are injected into the near-surface region of a substrate. High-energy ions, typically 10–200 kiloelectron volts in energy, are produced in an accelerator and directed as a beam onto the surface of the substrate. The ions impinge on the substrate with kinetic energies 4–5 orders of magnitude greater than the binding energy of the solid substrate and form an alloy with the surface upon impact. Virtually any element can be injected into the near-surface region of any solid substrate. Commonly implanted substrates include metals, ceramics and polymers. The most commonly implanted metals include steels, titanium alloys and some refractory metals.

During the Ion Implantation Process, a beam of positively charged ions of the desired element (either a gas such as nitrogen or a metal such as boron) is formed. Beam formation of a gas occurs by feeding the gas into an ion source. In the ion source, electrons, emitted from a hot filament, ionize the gas to form plasma. Ionization of the element is performed for the purpose of acceleration. Incorporation of an electrostatic field results in the acceleration of the positive ions at high energies under high vacuum (pressures below 10^{-5} Torr). The ions penetrate the component surface, typically to a depth not exceeding 0.1 µm. The near-surface alloy produced by implantation is different from conventional coatings in that the implanted ion is surrounded by atoms of the original surface material. Alloying at the surface can be as high as 50 atomic percent of the implanted element. It produces no discrete coating, nor will delamination of the altered surface occur.

DoD Need

Environmentally preferred surface protection and control

Army: P2-6

Navy: 2.I.01.g, 3.I.03.e, 3.I.04.h

Air Force: 608, 613, 805

Forming a beam of a solid element can occur by one of four methods. The first method is commonly used in the semiconductor industry, which requires extremely high-purity beams. In this method, a reactive gas, such as chlorine, is used to form the plasma. A metal chloride is generated as the chlorine ions chemically react with the metal walls of the ion source. The metal chloride then is ionized to form plasma of metal and chlorine ions. An analyzing magnet is used to separate the chlorine ions from the desired metal ion beam. The second method employs sputtering to generate metal ions. In this method, inert argon gas is ionized. The positively charged ions are attracted to a negatively biased metal target. As the argon ions strike the target, pure metal atoms and ions are dislodged from the target. The metal ions are extracted, focused into a beam, and directed toward the part to be implanted. Other methods of forming a beam of a solid are similar to that of the sputtering method. Variations of the sputtering method use thermal or electron beam evaporation, or cathodic arc (initiating an arc on the surface of a metal target to evaporate the metal) to generate the metal vapors. These

Located in the NDCEE Demonstration Facility, this technology has both ion implantation and ion beam assisted deposition capabilities.

methods do not require the costly analyzing magnets and provide very high ion currents.

Other possible products of this process are the formation of nitrides, borides or carbides, or the occurrence of localized alloying. With this process, properties such as hardness, wear resistance, corrosion resistance, and fatigue may be altered according to the selected implantation element. Ion implantation can provide 2–100-fold improvements in wear life, depending on the type of wear and service environment.

Technology Benefits and Advantages

- Reduces the use of hexavalent chromium, leading to reductions in environment, health and safety costs
- Reduces operational costs and labor requirements as a result of reducing the use of hazardous materials and the associated compliance procedures/processes
- Reduces operator exposure to hexavalent chromium
- Reduces waste generation
- Extends wear life of original components and reduces maintenance costs

Technology Limitations

- High capital costs (in the range of $500,000)
- Extensive training required for operators
- Line-of-sight limitations
- Limitations of surface area that can be treated

NDCEE FY01 & FY02 Accomplishments

- Produced a Demonstration Plan (FY01) that outlined the activities necessary to demonstrate selected EHC alternatives, including ion implantation, and the test methods and procedures used to evaluate the coatings and surface modifications. The alternatives were identified in a FY00 Potential Alternatives Report for Ion Beam and Plasma-Based Alternatives to Chrome Plating of Gas Turbine Engine Parts.
- Demonstrated the feasibility of using the ion implantation process to implant various materials for DoD propulsion applications. Chromium, titanium and titanium/nickel were implanted into 4340 steel substrates. Aluminum, phosphorous, titanium/nickel, tantalum and chromium were implanted into Inconel 718 steel substrates—one of the most prevalent materials in a gas turbine engine. The demonstrations were performed at vendor facilities (FY02).
- Performed corrosion, wear, adhesion and nanohardness tests on implants in accordance with the NDCEE Demonstration Plan to screen alternative coatings (FY02).
- Produced a Demonstration Report that documented the results of the demonstration/validation activities to determine the effectiveness of ion implantation (FY02). The results showed that the alternative process offered wear performance improvements.
- Performed an ECAM℠ analysis to evaluate the cost benefit of utilizing nitrogen ion implantation to modify the surface of EHC components (FY02).
- Produced a Justification Report that documented the technical justification of the alternatives recommended for further investigation (FY02).
- Produced a Final Report to document DoD and OEM component coating work completed by NDCEE and tested by various DoD and OEM sites (FY02).

Economic Analysis

The NDCEE conducted a cost-benefit analysis in which the EHC plating process at Anniston Army Depot was compared to EHC with supplemental ion implantation via beamline ion implantation for intermediate bearing housings. In general, the processing costs of beamline ion implantation were determined to be more expensive than EHC costs. However, with a five-fold extended service life over a 15-year analysis with a 3.2% discount rate, the calculations resulted in a payback period of nearly 11 years, an NPV of $806,000, and a 9.8% IRR. This finding reflects purely operational costs and should only be used as a guideline in understanding the cost differences in ion beam processes and EHC plating. The costs that were determined from the process data for EHC are $17.80 per square inch ($2.76 per square centimeter) and $44.90 per square inch ($6.96 per square centimeter) for ion implantation in addition to the EHC costs.

The ECAM℠ considered service improvements with the ion implantation process at a two-fold, three-fold and five-fold extended wear life. Wear performance improvements would be expected to increase part service life—the maintenance to rebuild worn parts, restore dimensional tolerance, and replace a worn or damaged coating, such as hexavalent chromium, would occur less frequently. Extended service life can lead to a decrease in total cost-of-ownership through engine overhaul cycle and labor hours and improved weapons system readiness. In addition, the ECAM℠ did not consider any environmental, health or safety savings. The reduced costs of waste disposal and regulatory compliance associated with hard chromium would add a cost savings to the analysis.

Suggested Implementation Applications

Any site using electrolytic hard chrome plating or other plating processes is a candidate for implementation.

Points of Contact

- Joe Argento, Industrial Ecology Center, (973) 724-2428, argento@pica.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- David Schario, NDCEE, (814) 269-6465, schario@ctcgsc.org

Applicable NDCEE Tasks

Sustainable Green Manufacturing (Task N.213, Subtask R4-6)
Pollution Prevention Initiative (Task N.227)

Lactate Ester Cleaning Technology for Weapon Systems

The NDCEE demonstrated and evaluated the feasibility of using lactate esters as both a depainting and cleaning technology. Demonstration findings revealed that the technology is presently suitable as a cleaning alternative, but while results are promising, the technology is not currently suitable as a depainting alternative. The NDCEE implemented a Lactate Ester Cleaning process at Anniston Army Depot in 2002.

DoD Need

Environmentally compliant cleaning methods

Army: CM-3, P2-1

Technology Description

From both a technical and economic perspective, lactate esters have been proven to be a viable alternative to P-D-680A Type II, commonly used in immersion and small-component spray (parts washers) equipment. They are not ideal replacements for blasting processes, which are quick, capable of recycling and relatively inexpensive. The lactate esters that were evaluated by the NDCEE did not perform well on the specific depainting applications attempted. Therefore, additional reformulation and evaluations are recommended.

Made from cornstarch or sugar, lactate esters are nontoxic, biodegradable materials with excellent solvent properties. Ethyl lactate is the ethyl ester of natural lactic acid. It is a clear, colorless, low-volatility liquid that is miscible with water and most organic solvents, has a low vapor pressure of 1.7 millimeters of mercury at 68°F (20°C) and a boiling point of 309°F (153.8°C). Ethyl lactate is commonly used in the food industry as a synthetic flavoring for cheese and animal feed. It is frequently combined in various proportions with methyl soyate or soy methyl ester (a solvent produced from soybeans) to obtain an increased flash point from 139°F (59.4°C) for pure ethyl lactate to greater than 150°F (65.6°C) for a blend. Blending with methyl soyate also suppresses the pungent odor characteristic of pure ethyl lactate.

On behalf of ANAD and other maintenance depots, the NDCEE evaluated the performance of three alternative blends by Vertec Biosolvents, LLC as cleaners: 50% ethyl lactate (EL) and 50% methyl soyate (MS), 70 EL/30 MS, and 30 EL/70 MS. These blends, as well as VERTEC™ Gold Paint Stripper, also were evaluated for their depainting capabilities. The lactate esters performed well as cleaners, ranging from 91–98% cleaning efficiency. These results compare favorably with that of P-D-680A Type II, a solvent widely used across DoD as a degreaser to remove lubricants, oils, carbon deposits, and other surface particulates and contaminants from aircraft and ground combat vehicle components. Based on the results of the demonstration activities and vendor recommendations, ANAD selected the 30/70 blend for implementation. Two primary benefits of this blend are its higher flash point and more pleasant odor than the other blends.

Anniston Army Depot has implemented a lactate esters bath to clean ground combat vehicle components, such as bearings, springs, housings and gears, from engines and transmissions.

Technology Benefits and Advantages

- Are nontoxic, biodegradable materials
- Produces results comparable to cleaners currently in use at DoD facilities
- Reduces or eliminates the generation of hazardous waste and release of hazardous materials into the environment
- Is compatible with most metal substrates
- Reduces worker health and safety risks by reducing or eliminating exposure to hazardous material usage
- Maintains or reduces the costs of cleaning operations
- Meets current and impending regulations

Technology Limitations

- Not presently suitable as paint strippers
- Not for use with polymeric materials and polyimide wire

NDCEE FY02 Accomplishments

- Produced a Requirements Report (FY02). The report identified the evaluation, testing and justification requirements needed to evaluate alternative cleaning and depainting processes. Baseline information was obtained during site visits at ANAD, Corpus Christi Army Depot, and Marine Corps Logistics Base, Yermo Annex.
- Produced an Alternatives Report that described the criteria used for selecting alternative cleaning and depainting lactate ester technologies and described the alternative technologies (FY02).
- Produced a Demonstration Plan that outlined bench-scale testing activities (FY02).
- Conducted performance and mechanical testing at qualified laboratories using the four selected lactate ester blends and two baseline materials. The mechanical evaluations included such tests as corrosion, adhesion, hydrogen embrittlement, refinishing properties, and compatibility with metal, polymers, and polyimide wire (FY02). The results of this testing were summarized in the Demonstration Report.
- Produced a Justification Report that discussed the results of an economic analysis (FY02). Both the technical and economic results were favorable for cleaning applications.
- Conducted a full-scale demonstration at the NDCEE Demonstration Facility (FY02) prior to equipment installation at ANAD. The 30EL/70MS blend was installed for cleaning into the transmission shop at ANAD.

Economic Analysis

The NDCEE conducted an economic analysis on two scenarios using the ECAM^{SM} tool, ANAD baseline data and demonstration results. Scenario 1 considered using lactate esters with a 6-month bath life as a drop-in replacement. Annual operating cost savings were approximately $44,800 with a discounted payback period of less than 3 months This scenario had capital costs of $9,550, which represented the purchase of five rinse tanks ($1,200 each) equipped with belt oil skimmers ($370 each) and $1,700 for refurbishment of existing vats for solvent compatibility. The 15-year NPV is projected to be $514,000; the IRR is 469%.

Scenario 2 included the installation of a parts washer equipped with filtration and using lactate esters with a 12-month bath life. Annual operating cost savings were $83,000 with a discounted payback period of approximately 19 months. Capital costs were $130,139, which represented the purchase of nine 200-gallon parts washers ($8,961 each), eight 80-gallon parts washers ($5,205 each) and five rinse tanks ($1,200 each) equipped with belt oil skimmers ($370 each). The 15-year NPV is projected to be $839,800; the IRR is 64%.

Suggested Implementation Applications

DoD sustainment facilities that clean weapon systems and components, particularly those that use immersion and small-component spray equipment. The NDCEE demonstrated the use of the 30/70 blend at ANAD on transmissions from the M88A1 and M113 tanks. Other potential transmissions that are maintained at ANAD are from the Light Armored Vehicle, Amphibious Assault Vehicle, M1, M60, and M9 Armored Combat Earthmover.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@daapgea050.apgea.army.mil
- Mark Napolitano, TACOM-ARDEC, (973) 724-3615, mnapolit@pica.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Laser-Induced Surface Improvements Process

The NDCEE demonstrated and evaluated the ability of the Laser-Induced Surface Improvements (LISI^{SM}) Process to apply a metal coating on two base metals. More specifically, a fatigue evaluation was conducted on 4340 steel substrates, chosen as representative of steels used in landing gear manufacturing. A corrosion resistance and shielding/grounding evaluation was conducted on 6061 aluminum substrates—an alloy used in the Mark 46 optical sight director.

Technology Description

The LISI^{SM} process is a controlled surface modification technique designed to tailor component surfaces to meet challenges such as corrosion or wear. The process begins by spraying an alloy precursor onto the substrate. Next, using a high-energy laser as the heat source, the precursor and the substrate are melted to form a new surface. The linear processing rate is 50–200 feet per hour, depending on the geometry of the part. The surface is modified from a depth of microns to 1 millimeter per single pass, depending on the substrate, precursor materials, and laser settings such as power, traverse rate, and focus.

Precursors play a vital role in obtaining desired properties such as wear and/or corrosion resistance. In addition, laser coupling changes with the chosen precursor. As a result, process settings must be modified whenever the material changes. Coupling is increased as wavelength decreases, so this type of treatment is likely to be more successful with diode lasers than with carbon dioxide or YaG lasers.

LISI^{SM} is a new technology with limited data available on the process. The theory behind LISI^{SM} is that because the surface composition is modified by alloying that occurs in part of the base metal, corrosion resistance is increased and surface adhesion problems do not occur. NDCEE demonstration results show that the chosen precursor determines corrosion resistance. In addition, the process may improve fatigue properties, but not for high-strength steels such as 4340, most likely because of their high ability to harden.

DoD Need

Environmentally preferred surface protection and control

Army: P2-6

Navy: 2.I.01.g, 3.I.03.e, 3.I.04.h

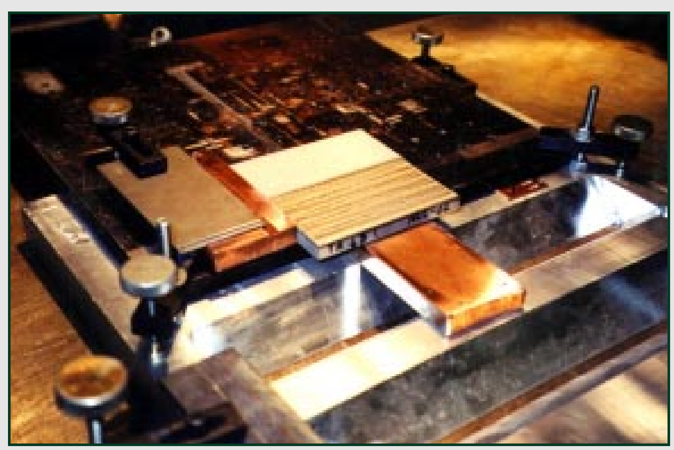
Air Force: 613

Technology Benefits and Advantages

- Produces little gaseous effluents and minimal hazardous waste streams due to nontoxic process
- Reduces or eliminates the use of hexavalent chromium (a known human carcinogen), leading to improved working conditions and reductions in environment, health and safety costs
- Reduces the operational costs and labor requirements as a result of eliminating hazardous materials and the associated compliance procedures/processes
- Extends wear life of original components and reduces maintenance costs
- Involves portable equipment, potentially enabling future in-field operation

Technology Limitations

- Laser treatment of high-strength steel is detrimental to fatigue performance.
- Process is currently limited to inner diameters greater than 2 inches and surfaces with no sharp corners or inner radius.
- Laser processing of some difficult-to-process materials such as high-strength steels, will likely involve post-processing operations, such as heat treatments to restore components to desired hardness levels or peening operations



Process setup showing high-strength steel slab approximately half way through LISI^{SM} treatment to impart beneficial compressive residual stresses.

- Laser-processed components currently require final machining/honing to achieve desired surface finish due to the relatively rough surfaces produced by the laser.
- Limited data are available on the LISI℠ process because it is a new technology.

NDCEE FY01 & FY02 Accomplishments

- Produced a Demonstration Plan (FY01) that outlined the activities necessary to demonstrate select EHC alternatives, including LISI℠, and the test methods and procedures that were used to evaluate the coatings and surface modifications. LISI℠ had been identified in an FY00 Potential Alternatives Report for Ion Beam and Plasma-Based Alternatives to Chrome Plating of Gas Turbine Engine Parts.
- Coated Army truck components using LISI℠ and completed rig and in-service testing with favorable results. The original equipment manufacturer that participated in the project was to continue further testing with the LISI℠ provider (FY01).
- Demonstrated the feasibility of using the LISI℠ process to apply chromium/chromium diboride on 4340 steel substrates. Under a separate, but related effort, the process was also used to apply iron-vanadium and iron-tungsten to 4340 substrates and nickel-copper and nickel-boron to 6061 substrates. The demonstrations were performed at vendor facilities (FY02).
- Performed corrosion, wear, adhesion and nanohardness tests on deposited coatings in accordance with applicable NDCEE Demonstration Plans to screen alternative coatings (FY02). Two FY02 Demonstration Reports were produced that documented the results of the LISI℠ demonstration/validation activities. While the LISI℠ process could provide the appropriate shielding/grounding properties, it could not consistently meet the corrosion requirements. In addition, laser treatment of high-strength steel was found to be detrimental to fatigue properties.
- Produced a Justification Report that documented the technical justification of the EHC alternatives recommended for further investigation (FY02). LISI℠ was not recommended.
- Produced two Final Reports, each reflecting a different purpose of the LISI℠ investigation (FY02).

Economic Analysis

LISI℠ has shown enough promise that, if combined with significant cost savings compared to current processes, further research and development may be in the Government's interest. At present, the operating costs per square foot for the hard chrome plating process of propeller hubs is estimated to be approximately $6. Cost data were obtained from NADEP-Cherry Hill by the NDCEE under a previous effort. The operating costs for the LISI℠ process is estimated to be $143; however, further maturation of the process is expected to reduce costs to approximately $27 per square foot (i.e., approximately four times as expensive as EHC plating). Such a higher process cost could only be justified through higher performance levels, which was not the case for the samples considered in the NDCEE studies, or through significantly lower environment, health and safety costs, which is currently not expected. However, a direct comparison of the costs between the two processes can only be performed upon scale-up of the laser-based surface modification process.

Suggested Implementation Applications

None at this time. The technology requires additional research and development.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Tasks

Pollution Prevention Initiative (Task N.227)
Surface Treatments for Enhanced Wear Resistance (Task N.245)

Micro-Electromechanical System for Detection of Corrosion Underneath Coatings

The NDCEE is identifying, investigating and developing micro-electromechanical system (MEMS) technologies that can be used to measure, control and prevent corrosion. Specifically, the NDCEE is designing, developing and testing prototype corrosion sensors for U.S. Army tactical vehicles. The purpose of these sensors is to detect the onset of corrosion underneath coatings to permit condition-based maintenance to reduce life-cycle costs.

Technology Description

Microdomain systems include those that are 10 centimeters in size and smaller. MEMS devices fall into this category and are typically thought of as having micro or micron-scale features. The term “MEMS” originally applied to silicon micromachined miniaturized electromechanical systems, but now refers to any subminiaturized system including chemical sensors and nonsilicon-based structures.

The NDCEE is currently developing and testing a linear polarization resistance (LPR) corrosion sensor. The sensor consists of several sensing elements, a data logging device and LabView™ software. Each sensing element consists of a set of interdigitized electrodes made from the same material as the substrate to be monitored and attached to a polymer sheet. The sensing element is approximately 1 x 2 centimeters in area and 50 microns thick. The current testing and development effort is focused upon developing reliability data and application techniques for future field testing.

Technology Benefits and Advantages

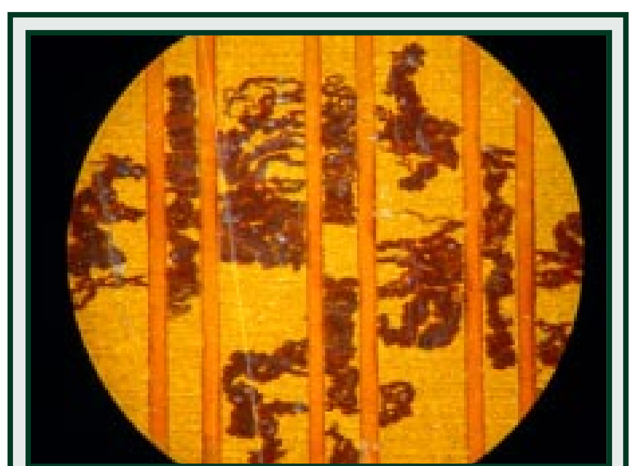
- Detects the onset of corrosion in vehicles
- Improves mission readiness through reduced risk of vehicle and equipment failure
- Reduces operator and maintenance costs associated with corrosion of ground vehicles
- Reduces development time and cost with use of more mature sensor technology
- Reduces the time and effort required to develop the sensor to where it can be field tested with the use of commercial-off-the-shelf software and equipment parts

Technology Limitations

- Still in testing and development stage
- High sensor cost in prototype quantities ($100 per sensing element)

DoD Need

Corrosion detection and prevention in tactical vehicles and equipment



MEMS sensors are designed to monitor corrosion of mild steel, typically used in military vehicle construction.

NDCEE FY01 & FY02 Accomplishments

- Designed, procured and conducted initial testing of LPR sensor (FY01)
- Began laboratory testing of LPR sensors (FY02)
- Began design phase of a second type of corrosion sensor (FY02)

Economic Analysis

Corrosion has a significant impact on the readiness, reliability and cost of ownership of weapons systems, support equipment and infrastructure. The estimated cost of corrosion to the DoD is $400 million per week, of which approximately one third is considered avoidable through the use of new and improved corrosion prevention or control techniques. Specific reductions in life-cycle costs associated with the use of corrosion-detection sensors are expected to be identified during field testing.

Suggested Implementation Applications

The corrosion sensor can be used on ground vehicles, aircraft, watercraft, equipment and munitions. Initial field testing and application is planned for ground vehicles.

Points of Contact

- Tom Landy, TACOM-ARDEC, (586) 574-8818, landyt@tacom.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Wayne Powell, NDCEE, (727) 549-7216, powellw@ctcgsc.org

Applicable NDCEE Tasks

Corrosion Measurement and Control Program (Tasks N.255 and N.304)

Microfiltration Systems

The NDCEE has extensive expertise with filtration systems. Several systems are featured in the NDCEE Demonstration Facility, where they are used by DoD and industrial facilities for demonstration and validation purposes. For instance, the NDCEE helped Red River Army Depot, Texas, to validate a microfiltration system as an aid to extending the solution life of its zinc-phosphate pretreatment baths and thereby increasing production efficiency. Most recently, the NDCEE installed three microfiltration systems at Tobyhanna Army Depot to be used in conjunction with its plating lines. The NDCEE also worked with Oklahoma City Air Logistics Center and Corpus Christi Army Depot in determining that the bath life of alkaline rust removers currently in use could be greatly extended by using a microfiltration system.

Technology Description

Microfiltration provides a 1.0–0.1-micron absolute barrier that removes emulsified oils, greases and particulate matter from filtered liquids, primarily alkaline cleaners. The typical configuration (known as cross-flow filtration) is a low-pressure (e.g., 5–40 pounds per square inch @ gauge), energy-efficient flow of liquid across the inner surface of a microfilter tube. Systems are available in different materials of construction and membrane pore diameters to accommodate unique bath characteristics (e.g., chemistry, volume and throughput).

These particular microfiltration modules are fabricated from graphite material formed into a tubular configuration. Wastes pumped into these tubes form a dynamic membrane that produces a high-quality filtration medium and removes all particles larger than the pore size. Turbulence helps to maintain membrane cleanliness, although periodic maintenance is recommended.

Applications include removal of heavy metal particles from semiconductor and components manufacturing as well as oil and grease removal from industrial laundry effluent and plating line cleaning baths.

DoD Need

Improved treatment of effluent discharges

Army: CM-5, CM7, CM-10

Navy: 2.II.01.q, 3.I.03.b, 3.I.11.b, 3.I.13.a

Airforce: 912

Technology Benefits and Advantages

- Removes suspended particulate matter, oils and greases from effluent discharges and reduces the frequency of bath changes
- Maintains a more stable bath consistency, thereby reducing process variation
- Reduces material and operating costs because chemical usage is reduced, secondary cleaning requirements (i.e., parts rework) are decreased, and less sludge/hazardous waste is generated/disposed
- Reduces worker health and safety risks by reducing chemical usage/handling
- Reduces waste solution discharges to industrial waste treatment plants
- May result in affordable payback period with system costs ranging $10,000–$30,000
- Helps facilities meet pretreatment standards for discharges of wastewater to treatment plants or effluent limits of NPDES permits

Microfiltration system

Technology Limitations

- Filtration membrane can become clogged with oil/grease if an oil coalescer is not used as part of the microfiltration process.
- Periodic cleaning of the membrane is required to optimize efficiency, adding to the operational cost of implementation.
- Proper sizing of the membrane is required to minimize loss of cleaner and/or surfactant.

NDCEE FY01 & FY02 Accomplishments

- Conducted a bench-scale demonstration at vendor facilities on four brands of microfiltration systems on behalf of TYAD (FY01). Based on performance results, a full-scale demonstration then was conducted on two of the systems (FY01/02). The demonstrations used cleaners that will be utilized in the Industrial Operation Facility at TYAD. Results of the testing were documented in a Demonstration Report (FY02).
- Performed a cost-benefit analysis using the ECAM^{SM} tool and projected parameters for the cleaning/plating lines at TYAD (FY02). Results were published in a Justification Report (FY02).
- Installed three Aqualogic MM-325 microfiltration systems at TYAD due to positive performance and optimum economic factors (FY02).
- Conducted bench-scale testing at the NDCEE Demonstration Facility that determined the bath life of alkaline rust removers currently in use by OC-ALC and CCAD could be extended (FY01/FY02). This testing was performed after determining that no cost-effective substitute for the current alkaline rust removers is available. Results are contained in FY02 Final Report.

Economic Analysis

The results indicated that installing microfiltration equipment would yield an acceptable payback period on three of the original seven plating lines initially under consideration at TYAD. Microfiltration systems from two manufacturers were considered: the MM-325 from Aqualogic, Inc. and the Silverback 150 from U.S. Filter Corporation. The MM-325 yielded a simple payback of 3.5 years, and the Silverback 150 yielded a simple payback of 4 years. While capital costs for the MM-325 were slightly higher than for the Silver back 150, $90,453 compared to $89,476, the MM-325 annual operating costs were lower: $58,403 vs. $61,566. Annual operating costs for the current process (no filtration) are $84,088. The MM-325 also offered a greater process throughput rate and better cleaning efficiency than the Silverback 150. The baseline process at TYAD does not currently recycle cleaning bath solutions.

Suggested Implementation Applications

This technology is applicable for any site with wastewater issues, particularly those connected with industrial operations such as electroplating lines. For instance, TYAD cleans and plates a wide variety of parts in all configurations and sizes from many DoD weapon systems. The parts are mostly from ground support equipment such as trucks and trailers. Other parts that are processed are from surveillance equipment, satellites, radios and other communication equipment. Two specific systems supported by TYAD are Guardrail™ and FireFinder™. Guardrail is a Corps Level Airborne Signal Intelligence collection/location system; FireFinder is a mobile radar system.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Tasks

Alternative Cleaning Solutions Recycle/Recovery (Task N.000-01, Subtask 5)
Pollution Prevention Initiative (Task N.227)

Municipal Solid Waste Conversion System

The NDCEE validated demonstration findings on a prototype Municipal Solid Waste (MSW) Conversion System. The findings indicated that the system can divert upwards of 90% of MSW from landfills and convert the waste into usable cellulose end products.

Technology Description

The MSW Conversion System converts typical household garbage, such as bottles, cans, organic wastes, trash bags and plastic milk jugs, into a sanitary cellulose end product by shredding, grinding and “cooking” the refuse in a hydrolyzer using high-pressure steam. The output cellulose pulp may be extruded into composite lumber planks for construction or, after two stages of separation, emerge as a “fluff” material that has potential reuse applications as a soil amendment. The proprietary process, developed by Bouldin & Lawson (B&L) Corporation, was demonstrated at the Fort Benning Materials Recovery Facility (MRF) in June 2002. The three-week NDCEE demonstration used raw municipal refuse from Fort Benning’s Military Family Housing (MFH).

Using a low-speed, high-torque shredder, the system reduces the raw municipal refuse into approximately 1–2-inch square pieces. Batteries, carpet and any other unusual items that might cause equipment or personnel harm are manually removed from the input stream. The shard pieces are delivered to a conveyor system that utilizes magnetic rollers to separate out the ferrous metals. The balance of the waste is then further reduced in a smaller shredder, ground, and conveyed into a hydrolyzer. This jacketed containment vessel uses high-temperature steam in a proprietary process to kill bacteria and viruses while breaking down carbon bonds in the material. The resultant hydrolysis product is transferred to an expeller unit (auger) that operates as a “hard” press. The internal screw-like shaft of the auger serves as a ram to shuttle the moist cellulose along an internally tapered tunnel. Water is removed from the aggregate cellulose in a rotary dryer, further ensuring the sterility of the pulp-like product. The coarse and fine cellulose mix is separated in a star screen; the coarse is deposited in a collection bin while the small fractions are tumbled through a rotary drum to remove the fines of aluminum, glass and plastic, which are gravity-fed into a “particulates” collection bin. The separated fine cellulose material emerges as a sanitized, sand-like granular fluff that may be useful as a soil amendment because of its organic base and relatively high nitrogen content. The coarse, peat moss-like material can be extruded into plastic-like composite planks.

DoD Need

Nonhazardous solid waste reduction

Army: P2-2

In addition to the solid output streams, the conversion system also releases excess water vapor from the boiler and internal chambers of the hydrolyzer. A portion of this steam is captured at the hydrolyzer-to-baler material transfer point and used to moisten the grinder infeed; however, water vapor is released and not captured from many points in the system. Humid air is also discharged from the dryer.

This prototype MSW Conversion System was successfully demonstrated at Fort Benning.

Technology Benefits and Advantages

- Converts MSW into cellulose end products, such as plastic-like lumber or material that has potential use as a soil amendment
- Processes over 90% of the unsegregated, base-generated municipal solid waste stream input
- Helps facilities meet a DoD Pollution Prevention Measures of Merit mandate for 40% (wt.) landfill diversion by 2005

Technology Limitations

- This system is still undergoing testing and has not been made commercially available. At this stage, without appropriate coordination and design intervention, a variety of suboptimum designs of this system could emerge on various military installations as a result of each agency's rushing to meet the Measures of Merit Reduction requirement and not coordinating efforts.
- Facilities will require appropriate regulatory permits.
- Output will be dependent on the composition of the MSW input stream. For example, Fort Benning's MFH MSW waste stream has a relatively low plastic content due to the efficiency of the base's recycling program. The low plastic content may result in poor structural properties of the extruded composite planks.

NDCEE FY02 Accomplishments

The NDCEE conducted a three-week demonstration at the Fort Benning MRF in FY02 in which 36.2 tons of raw material refuse was processed, leaving 3.3 tons segregated. At the conclusion of the demonstration, the B&L system had produced 10 tons of cellulose fluff for a future soil application study and 37 extruded 2-inch x 4-inch x 8-foot planks for subsequent CERL structural tests. The resultant cellulose end product realized an approximate 50% reduction in volume and 20% reduction in mass. In its current state of process development, the B&L conversion system can process over 90% of the unsegregated, base-generated MSW stream input. At this yield, as much as 18% of the total military-generated solid waste stream could be diverted from landfills.

Economic Analysis

According to the Army Environmental Requirements and Technology Assessments, solid waste diversion is a priority pollution prevention challenge for the U.S. Army. The military is faced with decreasing landfill space, increasing costs of disposal, and mounting environmental pressures for remediation of leaking landfills. The Army operates 17 active landfills that are rapidly filling and Army policy strongly discourages permitting new ones. The Solid Waste Annual Report states that during the first 3 quarters of FY99, the Army generated approximately 1.6 million tons of MSW, not including construction/demolition debris, at a disposal cost of $97.2 million. Costs are expected to increase dramatically over the next several years with the added pressures of mandated military environmental stewardship and remediation liability for older landfills that have started to leak.

An estimated total investment of $835,000 is necessary to acquire equipment comparable to that demonstrated at Fort Benning. ERDC/CERL calculated demonstration processing costs at $107 per ton. This cost included estimates for labor (engineering technician, forklift operator, maintenance electrician and general laborer), utility consumption (water, electricity and propane), and disposal for the segregated materials (3.3 tons).

The MSW Conversion System produces cellulose pulp that may be extruded into composite plastic-like planks (similar to the planks in white above).

Suggested Implementation Applications

This technology will benefit any facility or rapid deployment site that processes MSW. For instance, the U.S. Air Force is seeking a similar system that could "fit into a C-130" for rapid desert deployment.

Points of Contact

- Deborah Curtin, ERDC/CERL, (217) 398-5567, Deborah.R.Curtin@erdc.usace.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- James Failor, NDCEE, (727) 549-7084, failorj@ctcgsc.org

Applicable NDCEE Task

Nonhazardous Solid Waste (Task N.303)

Munitions Monitoring System

The NDCEE, in conjunction with the Physical Science Laboratory at New Mexico State University, is exploring the use of the Fiber Bragg Grating (FBG) sensor technology for a munitions monitoring system. As part of the investigation, several application and production issues were addressed, including conducting noise level, temperature, and random motion measurements as well as adhesive and fiber splice testing. For instance, tests were conducted to determine which adhesives are compatible with the sensors while providing the required bond properties.

Technology Description

The munitions monitoring system is being designed to constantly evaluate the structural integrity of munitions in storage and transit. Still in development, the system would replace the current predictive technology approach, which characterizes the storage conditions of a product and then predicts the product's degradation using models. These models may be based on either knowledge of the inherent degradation processes or on empirical data. Often, once a product passes a certain threshold based on the measured storage conditions, it is removed from inventory. A similar approach is the use of lot testing in which representative samples of each production lot are removed from storage for functional testing. If the units pass the storage conditions threshold, the entire lot is removed from inventory.

The key element of the munitions monitoring system is the use of the FBG sensor technology. This optical technology can measure mechanical strain and temperature in a variety of situations. Consequently, rather than merely monitoring the storage conditions to which products are subjected, it may be feasible and cost effective to monitor the underlying physical properties that are a direct indicator of possible product failure. Approaches to using them to measure other physical parameters (e.g., pressure, shock, acceleration and concentrations of certain gases) are under development.

As part of the evaluation process, a Munitions Test Fixture was designed to test the FBG in a configuration that closely resembled a 150-millimeter projectile. The test fixture consisted of nine pieces machined from low-carbon steel. One of the pieces was the test specimen, a 5.5-inch tall cylinder of aluminum, with a 6-inch outer diameter and a wall thickness of 0.058 inches. The test specimen was instrumented with three FBG sensors. Various experiments showed that the sensors could be used to measure the amount of deformation occurring in a test specimen.

DoD Need

Improved monitoring technique of munitions in storage and transit

Army: P2-5

Technology Benefits and Advantages

- Measures mechanical strain and temperature (with other physical parameters in development) in a variety of situations
- Provides immunity to radio frequency and electromagnetic interference due to the FBGs being entirely optical
- Obtains strain measurements that are better than those obtained with resistive strain gauges in terms of noise, repeatability, and stability
- Contains many sensors multiplexed on a single fiber, so that the "wiring" is simplified and cost per measurement is lowered
- Does not require electrical current at the measurement site (particularly beneficial to applications that involve explosives)
- Detects small dimensional changes, which are measured in terms of micro strain

The Munitions Monitoring System is being developed to constantly evaluate the structural integrity of munitions in storage and transit.

Technology Limitations

- Still under development

NDCEE FY01 & FY02 Accomplishments

- Produced a test report that summarized the investigative findings (FY01)
- Performed a literature review and industry survey to determine military needs and communications hardware/software protocol (FY02)
- Completed technology review and a field system design (FY02)
- Demonstrated a bench-scale munitions monitoring system (FY02)

Economic Analysis

Under current munitions monitoring applications, products that should be removed from inventory may not be discovered and/or products are removed unnecessarily. This situation can result in preventable production and disposal expenses as well as increased worker safety and health risks associated with replacing and disposing of products removed unnecessarily. Conversely, increased expenses and worker risks can occur with undetected product failures.

Suggested Implementation Applications

The munitions monitoring system is being developed to evaluate the structural integrity of munitions in storage and transit.

Points of Contact

- Joe Argento, Industrial Ecology Center, (973) 724-2428, argento@pica.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- David Schario, NDCEE, (814) 269-6465, schario@ctcgsc.org

Applicable NDCEE Tasks

Sustainable Green Manufacturing (Tasks N.213 and N.301, Subtask R2-14)

NitroCision™ CryoJet System

The NDCEE has significant technical expertise with coatings removal systems. As a result, the NDCEE was tasked to identify potential alternatives to chemical or mechanical coatings removal processes for use on delicate substrates, many of which are also dimensionally critical parts.

Technology Description

The patented NitroCision™ CryoJet System uses a high-velocity gaseous liquid nitrogen stream for cutting, cleaning, abrading and coatings removal applications. Coatings removal is achieved through a combination of temperature and pressure. The temperature and pressure of the liquid nitrogen stream can be adjusted to control the aggressiveness of the coatings removal. The only discharge from this system is harmless gaseous nitrogen and the removed coating material.

Developed by NitroCision, LLC, a subsidiary of TruTech, LLC, this skid-mounted system consists of a liquid nitrogen supply tank, a pre-pump to increase the stream pressure to approximately 15,000 pounds per square inch and additional intensifiers to increase the stream pressure up to approximately 60,000 pounds per square inch. The pre-pump and the intensifiers require a 480-volt, 200-amp, 3-phase power source. The nitrogen stream produced by this equipment can be controlled using a handheld wand (for use with lower pressures) or an automated control unit. Several nozzle configurations are available to adjust the approximate width of the spray path from 2–14 millimeters. Multiple spray nozzles can increase the width of the spray path to approximately 64 millimeters.

The NitroCision™ CryoJet process has demonstrated coatings removal rates up to 10 square feet per minute. The unit consumes approximately 2–3 gallons of liquid nitrogen per minute. The unit can be operated at pressure ranges from 12,000–60,000 pounds per square inch and temperature ranges from -391 to 212°F (-235 to 100°C). Adjustments to temperature and pressure control the aggressiveness of coatings removal. The effective range of the nitrogen stream is approximately 12 inches.

Technology Benefits and Advantages

- Eliminates hazardous airborne particulate from blasting operations, decreases solid waste, and eliminates the use of chemical strippers
- Reduces labor and operating costs as a result of decreased pre-removal preparation and post-removal cleanup
- Improves safety and worker health conditions due to the elimination of airborne emissions of heavy metals and other contaminants when used with vacuum recovery
- Helps facilities comply with Executive Order 13148, which requires DoD to decrease the amount of waste generated at federal facilities, as well as environmental regulations regarding airborne particulate emissions

Technology Limitations

- Is still under development
- Produces a gaseous nitrogen stream, which can be collected with the removed coatings using a recovery system
- Poses safety risks associated with the handling of the low-temperature liquid nitrogen and possible oxygen depletion when the system is used in confined areas
- Has line-of-sight limitations due to linear orientation of the nitrogen stream
- Requires operational and maintenance training

DoD Need

Environmentally preferred coatings removal technique

Army: CM-3, CM-9, P2-1

Navy: 2.I.0.1.g, 3.I.05.a

Air Force: 1232, 120, 225, 311, 814, 988, 1468

NDCEE FY02 Accomplishments

- Produced an Alternatives Report that identified the needs and requirements for alternative coatings removal technologies from delicate substrates (FY02). The NitroCision™ CryoJet System was recommended for evaluation of special hull treatment and passive countermeasure system tiles as well as radomes.
- Conducted a demonstration of the NitroCision™ CryoJet capabilities at the vendor facility in Idaho Falls, Idaho. Weapons system components that were demonstrated included a HMMWV hood, U.S. Navy and Air Force radomes, and PCMS tiles.
- Produced a Demonstration Report that summarized key results used to assess alternative coating removal technologies and compared their performance to the baseline removal methods (FY02). This alternative process was demonstrated at the vendor facility in Idaho Falls, Idaho.

Economic Analysis

The capital and operating costs of the CryoJet technology are currently unknown because the technology is still under development. However, some maintenance cost issues have been identified. Maintenance will include routine maintenance of the 100 horsepower pre-pump and other system components. The intensifiers will require seal replacement after every 400 hours of operation. The seal kit cost is approximately $1,200. The system also will require standard cleaning and inspection. Depending on the system configuration, additional maintenance of the recovery system and automation components may be required.

Suggested Implementation Applications

Additional system development and evaluation is needed before the CryoJet system is ready for implementation. Potential uses include coatings removal from Navy and Air Force radomes, HMMWV hoods, and antenna fairings.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org
- Georgette Kotsagrelos, NDCEE, (412) 577-2655, kotsagre@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Noncyanide Finishing Processes

The NDCEE was tasked to find alternatives to cyanide-bearing solutions used in plating operations, metal stripping and other finishing processes at Corpus Christi Army Depot and similar DoD facilities. As part of its tasking, the NDCEE identified and demonstrated candidate replacement technologies. Demonstration results showed that while the non-cyanide processes that were tested met some of the stakeholders' criteria, the test panels that were plated with these processes exhibited quality and adhesion problems and lacked the beneficial economic value to be considered as a suitable solution for CCAD.

Technology Description

Noncyanide finishing processes are designed to replace those containing cyanide, which is stringently regulated at federal, state and local levels because of its toxicity to humans. Less than 0.2 grams of cyanide can be a lethal dose for a 185-pound individual; therefore, it poses a severe hazard to those working on and around cyanide-bearing processes.

CCAD electroplating and stripping baths are sources of cyanide-bearing waste. The cyanide-based electroplating baths include copper, copper strike, silver plating, silver strike and cadmium. Cyanide-based stripping baths contain silver strip and silver solder strip (braze remover) solutions. Cyanide wastes are generated when parts with residual solution are rinsed after immersion in a cyanide-based bath or when spent baths are discarded. Bath solutions are rarely dumped and typically last several years. CCAD treats cyanide-bearing wastewater using an alkaline chlorination process. Cyanide-bearing waste streams are carefully segregated from other waste streams to prevent contamination with acid, which would cause the release of toxic hydrogen cyanide gas.

On behalf of CCAD, the NDCEE identified four potential alternative processes: cadmium plating, copper plating, silver plating, and silver stripping. Due to cadmium's inclusion on the EPA's list of 17 high-priority chemicals targeted for reduction and stricter regulation, this alternative was eliminated from consideration. The remaining three processes would be drop-in replacements, with some minor modification, for the cyanide-based processes.

DoD Need

Alternative non-cyanide finishing method

Army: P2-6

Navy: 3.I.03.e, 3.II.11.b

Technology Benefits and Advantages

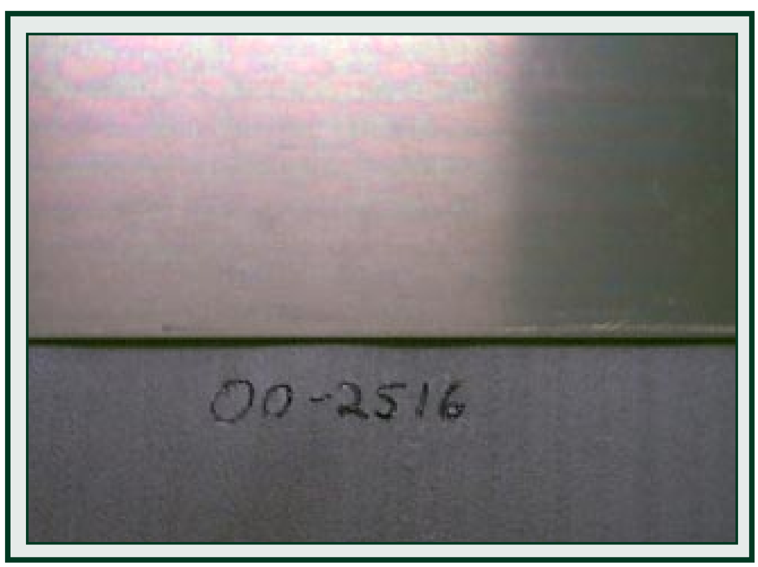
- Reduces or eliminates the use of cyanide, leading to reductions in environment, health and safety risks
- Eliminates the need for a separate waste treatment process in the Industrial Wastewater Treatment Plant
- Reduces the disposal of hazardous cyanide-bearing waste

Technology Limitations

- Requires higher capital and operating costs than cyanide-based processes
- May exhibit performance problems
- May require more user intervention and training than current processes

NDCEE FY01 & FY02 Accomplishments

- Identified 11 candidate replacement processes and performed an engineering assessment of the technical probability of success for each alternative (FY01).
- Down-selected to four processes based on CCAD operational requirements. These requirements were identified through a FY00 site survey at CCAD.



Panel plated with Zinex Silvergleam noncyanide silver plating

- Conducted performance tests on the three plating processes and one silver stripping process using a closed-loop electroplating line in the NDCEE Demonstration Facility (FY01–FY02). Demonstrations were also performed by the vendors in a laboratory scenario. Demonstration testing was conducted in accordance with a Demonstration Plan produced by the NDCEE (FY01). The substrates that were evaluated included 304 stainless steel, 7075 aluminum alloy, 2024 aluminum alloy, 4130 steel alloy, Inconel™ 718 and 4340 steel for hydrogen embrittlement testing. Test results were documented in a Demonstration Report (FY02). The analysis of the technical performance and cost of the alternatives versus the baseline processes was included in the Justification Report (FY02). The noncyanide process demonstration results indicated that the noncyanide copper and silver plating alternatives did not perform as well in the NDCEE Demonstration Facility as at the vendor facilities, indicating that the processes could require more user intervention and training than current processes. The noncyanide silver stripping performed successfully in stripping noncyanide silver plating at CCAD.
- Produced a Final Report that summarized the activities performed for CCAD (FY02).

Economic Analysis

The NDCEE, with the assistance from CCAD, identified several potential benefits and cost savings, but they were considered to be minimal. Additionally, implementation of the non-cyanide alternatives would increase capital and operating costs. Because of the limited benefits offered by the noncyanide alternatives, the NDCEE did not perform extensive data collection to quantify annual life-cycle costs. Therefore, indicators such as internal rate of return, net present value or discounted payback period were not calculated.

Suggested Implementation Applications

Noncyanide finishing processes may potentially replace cyanide-bearing solutions used in plating operations, metal stripping and other finishing processes. Maintenance shops use these processes on a variety of aircraft, vehicles and weapon system components. For instance, CCAD provides aviation maintenance for helicopter weapon systems including UH-60, AH-64, CH-47, UH-1, OH-58, MH-60, SH-60, and AH-1. However, the NDCEE found that the noncyanide finishing processes exhibited quality and adhesion problems when demonstrated in a production environment and lacked the beneficial economic value to be considered as a suitable solution for CCAD. This finding may be applicable to other facilities.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227)

Non-Line-of-Sight Alternatives to Hard Chromium Plating

Under a U.S. Air Force-sponsored effort, the NDCEE was tasked to identify, evaluate and validate environmentally acceptable alternatives to hexavalent chromium electroplating for non-line-of-sight (NLOS) applications. Generally, NLOS applications refer to complex-shaped components that possess internal diameters, blind holes, and other complex features. Subsequent site studies at three Air Logistics Centers revealed that 20–40% of the chromium-plated parts require NLOS processes for the refurbishment of coatings, which cannot be treated with HVOF technologies because of their line-of-sight limitation. This NDCEE effort was later expanded under a second task to include U.S. Army and Navy applications and additional NLOS alternatives.

Technology Description

The NDCEE has investigated the following four NLOS technology categories. For any of the evaluated processes to be considered a viable alternative to hard chromium, it had to meet or exceed specific performance characteristics, including guidelines outlined in the Federal Specification Chromium Plating (Electrodeposited) QQ-C-320B for Class II Engineering Plating, as well as pass additional requirements established by the NLOS Team.

Electroltytic Plating: Conventional plating equipment is used to deposit electrolytic coatings, and the process sequence is similar to hard chromium plating. The NDCEE investigated electrolytic nickel-tungsten (65% by weight Ni, 35% by weight W) and a nanoparticle electrodeposition process (Nanoplate). The Nanoplate process electrolytically deposits coatings that consist of nanocrystalline-sized nickel particles and the respective alloying element (e.g., molybdenum and cobalt). The coating evaluated by the NDCEE was the nickel-molybdenum alloy (99.5% Ni, 0.5% Mo).

Electroless Nickel (EN) Plating: This process is also known as chemical or autocatalytic nickel plating. In contrast to the electroplating (galvanic) technique, this chemical nickel plating process works without an external current source. The plating operation is based upon the catalytic reduction of nickel ions on the surface being plated. There are three main types of EN coatings: nickel-phosphorus (ENP), nickel-boron, and poly alloys. The most popular ENP is generally used for engineering applications. It is deposited by the catalytic reduction of nickel ions with sodium hypophosphite in acid baths. Variations on the ENP process include ENP with boro-nitride particles and ENP silicon carbide. Nickel-boron is primarily used in industrial wear applications for its as-plated hardness, which is higher than that of nickel-phosphorus. Poly alloys are a combination of nickel, boron or phosphorus and other metals such as cobalt, iron, tungsten, rhenium or molybdenum. Composite deposits such as EN-polytetrafluoroethylene and EN-diamond have been developed for special applications.

DoD Need

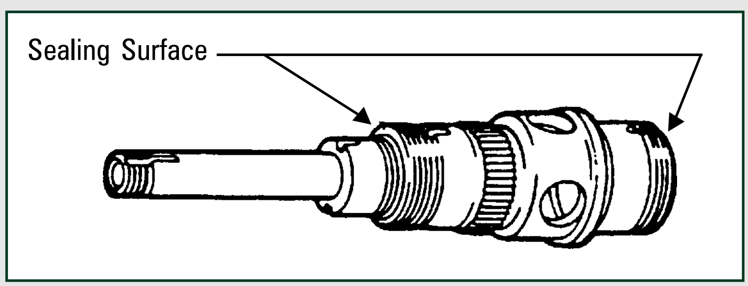
Surface protection and corrosion control

Army: P2-6

Navy: 2.I.01.g, 3.I.03.e, 3.I.04.h

Air Force: 613, 805

Iron Plating: Electrolytic hard iron has been produced and utilized for a number of years. Its use has been limited to applications in which wear resulting from lack of lubrication was not a consideration. The process is extremely complicated when used to achieve both desirable and functional metallurgical properties. However, the majority of iron plating solutions are stable and easy to operate. Most electrolytic iron is highly



This aeronator valve, which is a component treated at Oklahoma City ALC, is an example of an NLOS application.

stressed and brittle and it, as well as the basis metal, is highly subject to hydrogen embrittlement. Iron's primary uses include, but are not limited to, protection of soft or perishable metals and alloys, reinforcing fragile metal forms and providing a magnetic surface on nonmagnetic materials. A number of iron plating bath solutions are available and commonly include chloride, sulfate, fluorborate, sulfamate and other proprietary solutions. The iron plating process that was investigated by the NDCEE achieves an electroplate with a microstructure that enables it to resist wear and coining. This reclamation process has been proven over the years to be able to restore worn, improperly machined or salvaged service parts.

Trivalent Chromium Plating: This process eliminates the use of chromic acid, thereby reducing health risks to operators. Trivalent chromium forms insoluble mineral precipitates in groundwater, which eliminates the chemical reduction step in wastewater treatment. As a result, the treatment process is simplified and overall treatment costs are reduced. The trivalent chromium plating process that was investigated under this effort is deposited electrolytically, but no special fixturing or racking is required. Carbon anodes are recommended for this process, as is an ion exchange unit for the removal of contaminants from the plating bath.

Technology Benefits and Advantages

- Improves safety and worker health conditions due to the reduction or elimination of hexavalent chromium
- Reduces the operational costs and labor requirements as a result of eliminating hazardous materials and the associated compliance procedures/processes
- Reduces operator exposure to hexavalent chromium
- Reduces waste generation
- Produces coatings that are in accordance with the requirements listed in Federal Specification QQ-C-320B and are easily removable
- Extends wear life of original components and reduces maintenance costs

Technology Limitations

- The trivalent chromium process investigated requires a licensing agreement.
- The iron plating process investigated is extremely complicated when used to achieve both desirable and functional metallurgical properties.
- The trivalent chromium and the electrolytic plating processes require additional technology development prior to implementation.

NDCEE FY01 & FY02 Accomplishments

- Performed site surveys at Anniston Army Depot, Naval Aviation Depot–Jacksonville, Naval Aviation Depot–Cherry Point, and Naval Aviation Depot–North Island to identify NLOS chromium-plated parts, the coating requirements for those parts, and relevant processing methods for each part (FY01).
- Identified and assessed three NLOS technologies to apply various coatings for DoD NLOS applications: trivalent chromium plating, electroless nickel plating, and iron plating (FY02).
- Prepared and submitted a Requirements Report, Alternatives Report, Demonstration Plan, Demonstration Report, Justification Report, Implementation Report, and Final Report (FY02). These reports document the Army and Navy requirements, the selected alternatives, the demonstration activities, the economic analysis for the best performing alternative, and the plan for implementing that alternative.
- Prepared and submitted a Final Report that detailed the efforts conducted on behalf of the Air Force (FY02), with a special emphasis on findings from Level Two Screening Testing. Level Two evaluations included Taber (abrasive) wear tests on vendor-coated panels. For Level One Screening Tests conducted in FY01, six

coating processes were selected for evaluation based on an NDCEE-designed decision tool. The tool incorporated client criteria and results from a market survey. During this evaluation process, the NDCEE traveled to most vendor sites to observe the applicable process as well as record optimization techniques. Based on results and vendor comments, four processes were chosen for the Level Two tests.

Economic Analysis

Using the ECAM℠ tool, the NDCEE performed an economic analysis on two NLOS alternatives: EN and iron plating processes. An ECAM℠ was not performed for the trivalent chromium or electrolytic plating processes because demonstration test results revealed that further technology development was required for these processes.

The ECAM℠ for the EN plating process showed that this technology is not cost effective. The NDCEE recommended that no further action be taken with this technology until it can be further refined and shown to provide a potential for cost savings.

For the iron plating process, two ECAM℠ scenarios were completed. The ECAM℠ revealed that the annual costs for Scenario 1 (EHC processes are successfully converted to the HVOF process for line-of-sight components and the iron plating process for NLOS components) were approximately one third less than the baseline costs. The annual cost savings were $10,829.29, and the simple payback period was less than 2 years. The NPVs after 5, 10, and, 15 years were in excess of $30,000, $70,000, and $100,000, respectively. Also, the IRR values ranged 49–56%. The ECAM℠ results for Scenario 2 (all hexavalent chromium processes were not converted) showed that if hexavalent chromium cannot be completely replaced, the scenario for the use of iron plating is not cost efficient. The NPVs all show negative values that indicate a loss, and no values for IRR and payback period indicate that no return is expected on this investment. Two preliminary cost analyses were performed using different assumptions in each scenario.

Suggested Implementation Sites

DoD maintenance facilities that use hexavalent chromium compounds for the repair of worn coatings. Approximately 20–40% of all hard chromium plating activities at Air Logistics Centers are completed for NLOS applications.

Points of Contact

- Thomas Naguy, Wright Patterson AFB, (937) 656-5709, thomas.naguy@wpafb.af.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org
- Milissa Pavlik, NDCEE, (814) 269-2545, pavlik@ctcgsc.org

Applicable NDCEE Tasks

Pollution Prevention Initiative (Task N.227, Mod 1)
Non-Line-of-Sight (NLOS) Hard Chromium Alternatives (Task N.229 and Task N.229, Mod 1)

Oxygen Line Cleaning Systems

The NDCEE validated demonstration findings on two types of oxygen line cleaning systems (aqueous and solvent) that replace traditional cleaning systems that use ozone-depleting substances (ODSs). These systems will help DoD meet its mandate to eliminate the usage of ODSs throughout the Services.

Technology Description

Oxygen line cleaning systems are used to remove contaminants (oil, particulates, grease, etc.) from the insides of oxygen lines and other equipment used in aerospace vehicles, surface ships and submarines. Traditional cleaning methods use solvents containing chlorofluorocarbons (specifically CFC-113) and hydrochlorofluorocarbons (specifically HCFC-141b), both classified as ODSs under the Clean Air Act. The Act mandated the termination of production of class I ODSs (CFCs) by January 1, 2000. The phase-out of Class II ODSs (HCFCs) is scheduled to start in 2015.

The Navy Oxygen Cleaning System (NOCS) process is an off-aircraft aqueous cleaning system. It is applicable for use with lines not exceeding 6 feet in length and 1 inch in diameter and items that can be fully immersed in an ultrasonic tank, which is 1.9 gallons in size for the NOC system. The system utilizes a five-step process:

1. Use pneumatic pump to flush tubes with an aqueous cleaning solution, heated to 150°F, for 30 minutes and then backflush the line for another 30 minutes
2. Rinse tube interior with deionized water, heated to 150°F, for 30 minutes
3. Purge line for 30 minutes with hot nitrogen, water pumped, Type I, Class I Grade B, NIIN 00-985-7275
4. Dry part
5. Return part to aircraft.

The Versar Company on-board system and the Northrop-Grumman off-aircraft system are both solvent-based systems housed in a cleaning cart. The following are the major process steps used for both systems:

- Cleaning cart attached to oxygen system
- Leak detection cycle
- Wash cycle for 15–20 minutes
- Cleanliness verification
- Rinse cycle
- Evaporation cycle
- Hot air purge halogen detection cycle
- Cleaning cart detached from oxygen system and return to service.

DoD Need

Alternatives to ODS solvents for cleaning of military line applications such as oxygen line systems

Navy: 3.II.03.a, 3.II.03.b

Both the Versar and Northrop-Grumman systems utilize a zero-ODS cleaning solvent, HFE 7100. Manufactured by 3MTM, HFE-7100 is a clear, colorless and low-odor fluid and is officially listed as a nonvolatile organic compound by the Environmental Protection Agency (per the 8/25/97 *Federal Register*).

Oxygen Line Cleaning System Target Hazardous Material Summary

Target Hazardous Material	Current Process	Applications	Current Specifications	Affected Programs	Candidate Parts/ Substrates
Ozone-depleting chemicals (CFC-113, HCFC-141b)	Flush CFC-113 or HCFC-141b through contaminated oxygen lines and vent directly to atmosphere	Aerospace vehicles Navy: Removed oxygen lines only	MIL-STD-1330D, MIL-STD-1359, SAE ARP-1176, A-A-50427 Individual vehicle technical orders	Air Force: B-1, B-2, F-15, F-16, C-130 Navy: Eventually all platforms NASA: Orbiter	Aluminum, stainless steel, copper

The table on the previous page summarizes the target hazardous material, current process, applications, current specifications, affected programs and candidate parts/substrates.

Technology Benefits and Advantages

- Improves safety and worker health conditions by eliminating the usage of hazardous materials
- Helps facilities meet reporting thresholds for solvents under SARA Title III (40 CFR 300, 355, 370, and 372) as well as Executive Order 13148, Greening the Government Through Leadership in Environmental Management

Technology Limitations

- Some systems are applicable to lines of all sizes and diameters, while others may only be applicable to lines with small diameters and lengths.

NDCEE FY01 & FY02 Accomplishments

- Produced Joint Test Protocol (J-99-CL-015-P1) for Validation of Alternatives to Ozone Depleting Chemicals Used in Oxygen Line Cleaning (FY01). The Joint Test Protocol (JTP) contains the test conditions and acceptance criteria for qualifying alternatives, as provided by the stakeholders. The selection criteria were determined by a joint group led by Joint Group on Pollution Prevention and consisting of technical representatives from Oklahoma City Air Logistics Center, NASA, Naval Air Systems Command, Northrop-Grumman, and B-1, B-2, F-15, and F-16 weapon system personnel. Different substrates, contaminants and line sizes were given in the JTP to be tested.
- Validated demonstration findings on non-ODS cleaning options. Demonstration results passed test acceptance criteria, indicating that the solvent and selected cleaning methods were sufficient for cleaning nearly any type of line (hydraulic, fuel, coolant, environmental, etc.) on several different applications such as tanks, machinery and hospital oxygen lines. Tests included moisture testing for onboard cleaning, particle count testing for off-aircraft cleaning, and materials compatibility testing (using 16 substrate types) (FY02).
- Produced Joint Test Report (J-99-CL-015-R1) for Validation of Alternatives to Ozone Depleting Chemicals Used in Oxygen Line Cleaning (FY02). All JG-PP reports and test data are available to government and industry through the JG-PP Web site located at www.jgpp.com.

Economic Analysis

No cost-benefit analysis was conducted. However, DoD has a mandate to eliminate the usage of ODSs from all military applications. Furthermore, the non-ODS oxygen cleaning systems meet a specific DoD high-priority need for alternatives to ODS solvents for cleaning of oxygen systems.

Suggested Implementation Applications

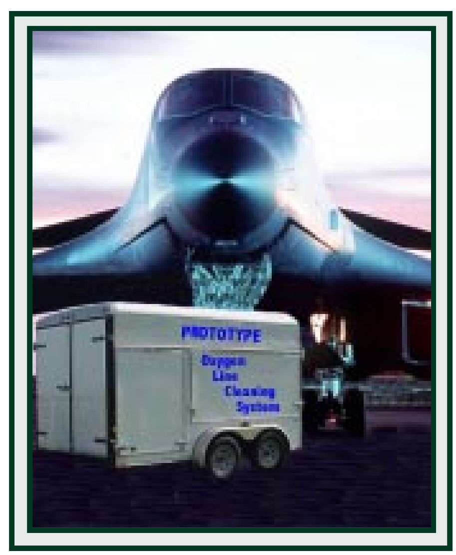
This technology can be used at any DoD facility responsible for cleaning equipment that has a line (hydraulic, fuel, coolant, environmental, etc.). See table on previous page for affected military programs.

Points of Contact

- Mary Hayes, WPAFB, (937) 656-3679, mary.hayes2@wpafb.af.mil
- Albert Walker, ODASA(ESOH), (410) 436-6867, Albert.Walker@daapgea050.apgea.army.mil
- Ronald Patun, NDCEE, (814) 269-2719, patun@ctcgsc.org

Applicable NDCEE Task

Engineering and Technical Services for Joint Group on Pollution Prevention (Task N.272)



This B-1 aircraft is being serviced with a Versar Oxygen Line Cleaning System cart.

Particle Separation

The NDCEE demonstrated and validated a particle separation technology for its ability to remove particulate metals from soil. The demonstration test was performed on 3,500 tons of lead-contaminated soil from a small arms firing range. Based on initial and final lead levels, the technology reduced total lead levels in the soil by 93%. However, variations in soil structure, gradation, chemistry and contaminant concentrations will result in recovery rates that are site- and cost-specific and cannot be universally applied. For instance, one site may contain a high level of leachable lead due to acidic soil conditions, while another site may contain predominately particulate lead due to more neutral soil conditions.

Technology Description

The particle separation technology uses a modified placer mining technique to remove particulate metal, such as spent bullets and bullet fragments, from soil. The recovered metal can be sent to a recycling facility. Depending on the nonparticulate metal concentration levels, the soil may require additional treatment such as stabilization.

The NDCEE demonstration test was performed at Fort Dix. Bench-scale treatability study results indicated that site soils were composed primarily of sands containing an oversized fraction of plus-No. 10 sieve size (0.0787-inch) particulate metal, rock and vegetation. The deployed unit process system consisted of several physical components integrated into one continuous process. The components included a wash plant, gravity separation unit, soil dewatering, clarification and fines dewatering, water storage and management, and recovered metal management.

The process began with the removal of soil from the face of the firing range berm. The soil was then processed over a wet vibrating screen deck that was equipped with a No. 10-mesh (0.0787-inch) screen. Soil was fed into the plant through a grizzly feeder and was subsequently conveyed to the wet vibrating screen deck. This conveyor was equipped with a belt scale for recording the production rate and daily tons of soil processed. The plus-No. 10 size fraction, consisting of rock, particulate metal and vegetation was then conveyed into a gravity separation unit, which was comprised of two parallel jigs that were operated in an alternate batch mode, with the metal removed as required. The recovered metal particles were piped to a dewatering/bagging module where they were put into containers. The physically treated sand fraction was dewatered and then discharged to a loader via a conveyor.

Following physical treatment for removal of the particulate metal, the plus-No. 10 sieve size fraction, now consisting only of rock and vegetation, was dewatered and discharged to the treated soil stockpile. The minus-No. 10 sieve size fraction, consisting of fine sand, silt and clay, was transferred to a clarifier where a nonhazardous, nonionic coagulant was added to settle the fine particle size material from the water. The settled fraction was then discharged onto a high-frequency screen deck for final dewatering, with subsequent discharge to the treated soil stockpile. Recovered water from the clarifier was reused within the plant.

DoD Need

Removal of particulate inorganics from soils

Army: R-4

Air Force: 567, 2502

Navy: 1.I.01.1, 1.I.04.j

Technology Benefits and Advantages

- Removes contaminants from the soil rather than transferring them to a landfill; thus, potential long-term risks to human health and the environment are eliminated.
- Generates reusable products for recycling. Under 40 CFR 261.6(a)(3)(iv), recycled scrap metal is classified as a “recyclable material” that is not subject to the requirements for generators, transporters and storage facilities of hazardous wastes specified in paragraphs (b) and (c) of 40 CFR 261.6. Therefore, the scrap metal reclaimed from the firing range soil does not need to be regulated or manifested as a hazardous waste during generation or transport to a smelter for recycling.

- Provides some reduction in the volume of the waste streams. Volume reduction is typically less than one percent, depending upon the composition of the waste streams (i.e., heavy metal particle size and concentration). Corresponding benefits include reduced storage, handling and shipping costs, in addition to increasing the life of landfills because less waste will be disposed at those facilities.

Technology Limitations

- Substantial initial investment in equipment and staff training is required.
- A thorough treatability study is required to determine whether physical separation would be technically feasible and cost effective in reducing the total heavy metal concentrations of the soil, based on site-specific soil conditions and contaminant levels.
- Air, water and other permits may be needed; however, the demonstration revealed air emissions met Clean Air Act standards and the process generated wastewater that could be recycled back into the system.

NDCEE FY01 & FY02 Accomplishments

The NDCEE completed demonstration/validation activities, including a cost-benefit analysis and final report, at small arms firing range (SAFR) 24, Fort Dix (FY02). During the three-year demonstration, 3,589 tons of physically treated soils were treated to below the New Jersey residential site standard for total lead, averaging 396 milligram per kilogram. Based on initial and final lead levels, the particle separation technology reduced total lead levels in the soil by 93%. Air monitoring during physical treatment revealed no hazardous dust or lead emissions. Based on these findings, the demonstration revealed that physical treatment may be ideal when applied to SAFR with appropriate soil, environmental and range conditions, such as those present at SAFR 24. Physical treatment results in a recyclable lead product, clean soil and a permanent solution.

Economic Analysis

Projected Full-Scale Particle Separation Costs

Assumptions

- Three adjacent SAFR would be treated yearly at Fort Dix.
- The minimum quantity of soil to be processed annually would be approximately 30,000 tons.
- The physical separation operations would be situated within the confines of the range.

Impact Berm Soil Estimated Disposal Costs

Description	Unit Cost	Total Cost
Disposal Charges: 3,500 tons New York State Hazardous Waste Fee	 $125.00 $26.50	 $437,500 $92,750
Freight Charges (roll-off containers, liners, surcharges)	$79.94	$279,773
Labor/Mobilization	Lump	$13,062
Equipment	Lump	$28,519
Total	$243.32	$851,604

The particle separation technology removed bullets from Fort Dix soil.

- The unit cost for physical separation processing incorporates the costs associated with mobilization/demobilization, mobile (temporary) utilities (e.g., electrical power and water), recycling of the recovered lead, berm soil excavation and transportation, and site restoration/berm reconstruction with the processed soil.
- The components of the physical separation plant would be similar to those used in the demonstration project, but up-scaled in size to account for higher production.
- Regulatory permits can be obtained.
- An additional particulate metal recovery circuit will be added to recover fine-sized particulate metal for more consistent total lead results, resulting in a lower-weight-averaged total lead value for the treated stockpile.

Unit Cost Estimate

In accordance with the foregoing assumptions, the projected full-scale physical separation unit cost estimate is $60 per ton. For a long-term project that would include the physical processing of soils from all of the SAFRs at Fort Dix, the unit cost could be reduced further because the costs associated with mobilization/demobilization would become one-time events, which would be applied to the entire quantity of soil processed.

Baseline (Conventional) Unit Cost Estimate

The baseline approach to manage SAFR soils is excavation and off-site disposal at an approved facility. Because the impact berm soils routinely qualify as a characteristic hazardous waste, RCRA requirements apply to the excavation, transportation and disposal of these soils. A comparison cost estimate for excavation and off-site disposal at a secure RCRA disposal facility was prepared and is summarized in the table on the previous page. As a review of this table indicates, this unit cost is approximately $243 per ton.

Comparison to Baseline

The difference between the projected full-scale physical separation unit cost estimate and the conventional excavation and off-site disposal unit cost estimate is $183 per ton. For a full-scale project that encompasses 30,000 tons, this differential represents a cost savings of approximately $5,490,000.

Suggested Implementation Applications

Any location with inorganic soil contamination is a candidate. According to the Army Environmental Requirements and Technology Assessments, 477 unique sites at 74 U.S. Army installations are from 9 Major Commands (MACOMs) with confirmed inorganics soil contamination, and 80 unique sites of 17 Army installations from 4 MACOMs had suspected soil contamination. In addition, long-term monitoring of inorganics in soil was needed at 63 unique sites of 19 Army installations from 4 MACOMs.

Points of Contact

- Darlene Bader-Lohn, ODASA(ESOH), ACOR, (410) 436-6861, darlene.bader-lohn@aec.apgea.army.mil
- James Dawson, NDCEE, (303) 297-0180, dawson@ctcgsc.org

Applicable NDCEE Tasks

Demonstration of RangeSafe System at Ft. Dix, NJ (Range 24) (Task N.204)
Demonstration of RangeSafe Particle Separation and Stabilization Technology at Range 25, Fort Dix (Task N.257)

Photochemical Depainting System

The NDCEE has evaluated the feasibility of using the prototype Photochemical Depainting System to remove coatings from radar domes (radomes) or radome pieces. Development of this system has significant implications to SIMA Mayport Paint Shop, Tinker AFB and other depots where radomes are depainted.

Technology Description

The Photochemical Depainting System removes coatings from parts without the aid of chemicals, and therefore, without emitting VOCs or HAPs. The system replaces other coating removal processes, such as hand sanding, the use of abrasive media, VOC- and HAP-containing strippers, and acid-based strippers.

Developed by Green Oaks Research Laboratory, Inc., the system consists of intermittent exposure of a sample to a stripping media and ultraviolet (UV) light. A stripping media of polyethylene oxide (PEO) and hydrogen peroxide (H_2O_2) is sprayed onto the coated substrate, causing the coating to eventually detach. Spray times and UV exposure times vary, but the total average exposure times have ranged 2–8 hours.

During Phase II of a Small Business Innovative Research Program, funded by Naval Air Warfare Center Aircraft Division, the process was transitioned from laboratory scale to an automated field unit capable of handling up to a 5-foot x 5-foot low-profile components.

The initial proof-of-concept involved altering the process variables, including the UV photon flux, H_2O_2 levels, infrared heating and PEO concentrations. The tests were extended to a wide range of paints and primers including epoxies, polyurethanes, acrylics and lacquers. Various substrates of wood, stainless steel, aluminum and composites were tested. Initial results showed successful removal of the paint with no visible impact or damage to the substrate.

Technology Benefits and Advantages

- Reduces or eliminates both the generation and release of hazardous waste/ materials into the environment
- Reduces worker exposure to VOCs/HAPs, reducing lost work time and health care costs
- Meets or increases the production and maintenance goals without any degradation of part quality

Technology Limitations

- Technology is in the developmental stage and has only been demonstrated on test pieces and radome pieces.
- Scale costs to accommodate large aircraft components are unknown.
- Substrate damage is unknown.

NDCEE FY02 Accomplishments

- Obtained baseline information and requirements for a technology demonstration from SIMA Mayport Paint Shop and Tinker AFB. The findings were documented in a Requirements Report (FY02).

DoD Need

Environmentally compliant paint removal method

Air Force: 1232, 225, 580, 814, 988, 1468, 120, 311

Navy: 2.I.01.g, 2.I.01.q, 3.I.05.a

Army: CM-3, P2-1

Military aircraft should benefit from the Photochemical Depainting System currently in development.

- Produced a Demonstration Plan that was used by the technology developer to conduct a demonstration using the Photochemical Depainting System for removing coatings from a variety of radome substrates (FY02).
- Performed an economic analysis using the ECAM^{SM} tool and baseline costs provided by SIMA Mayport (FY02). The analysis was conducted assuming the photochemical depainting would be a replacement for hand sanding of radomes.
- Produced a Demonstration and Justification Report that provided the technical and economic findings of the NDCEE evaluation of the depainting system (FY02). U.S. Navy personnel deemed the removal of the coatings from Navy radome pieces satisfactory after inspection. The ozone monitoring results showed that the time-averaged ozone generation from the booth is insignificant from a health hazard perspective.

Economic Analysis

The ECAM^{SM} indicated a payback of 5–11 years based on the estimated capital expenditure of \$100,000–\$200,000. Because the Photochemical Depainting System is still in the development stage, this analysis is based on the estimated costs for this technology. Therefore, the NDCEE recommends that another cost-benefit analysis be conducted when more precise capital and operating costs become available.

Suggested Implementation Sites

Any DoD sustainment facility that uses manual depainting methods or chemical strippers to remove coatings from components, such as U.S. Navy and Air Force radomes and aircraft components, such as those from a C5 aircraft would benefit from this system.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227)

Two views of the prototype Photochemical Depainting System

Physical Vapor Deposition Systems

The NDCEE has demonstrated and evaluated the feasibility of using Physical Vapor Deposition (PVD) Systems to deposit several coatings types on a variety of substrates. The NDCEE has determined that PVD Systems can be used to extend original component life, thereby resulting in a reduced frequency of hard chromium plating on a per part basis. EHC is used by most DoD maintenance facilities to refurbish gas turbine engines.

Technology Description

PVD processes are film deposition processes in which atoms or molecules of a material are vaporized from a solid or liquid source and transported in the form of a vapor through a vacuum or low-pressure gaseous environment, then condensed on a substrate. The NDCEE conducted demonstrations of the following four PVD technologies as alternatives to EHC.

Cathodic Arc Deposition: This process has emerged as one of the most powerful and versatile technologies that can apply a high-performance, hard coating at temperatures below 800°F. It may be used to evaporate almost any metal or alloy. Other key advantages of using cathodic arc are high deposition rates with excellent coating uniformity. Coating uniformity is attributed to the improved throwing power of the process, as compared to conventional PVD processes. The throwing power results from the high ionization of coating material. The high percentage of coating material ionization, combined with substrate biasing leads to excellent film adhesion and denser coatings than conventional PVD processes. In general, good quality films are deposited throughout a wide range of deposition conditions. Another key advantage of cathodic arc is the minimal amount of waste generation incurred. Waste generally consists of pump oil and possibly small amounts of dry, flaky coating materials.

DoD Need

Surface protection and corrosion control

Army: P2-6, P2-11

Navy: 2.I.01.g, 3.I.03.e, 3.I.04.h

Air Force: 613, 805, 608

Ion Beam Assisted Deposition (IBAD): IBAD is a coating process that aims to improve density and adhesion and control the microstructure of the coating. It incorporates both a means of PVD and simultaneous energetic ion bombardment. Unlike other PVD systems, IBAD offers full-density coating due to the bombardment of high-energy ions and the tailoring of process parameters. The fatigue strength of components also can be improved. Like glass bead peening, the high-energy, bombarding particles create residual compressive stress on the surface of components that can improve the fatigue strength of materials. This benefit can be significant for some critical components such as aircraft landing gear. IBAD is used to deposit coatings at low temperatures, which makes the process highly versatile for temperature-sensitive materials.

Plasma Immersion Ion Processing (PIIP): PIIP is a relatively new vacuum technology for the application of hard, wear-resistant coatings. Like conventional PVD methods, PIIP is used to deposit various coatings, but the non-line-of-sight PIIP approach allows

With this PVD technology, components are placed within the chamber and then coated.

simultaneous treatment of large components and complex shapes without requiring component manipulation. The same equipment can be used to deposit coatings from hydrocarbon gases or organometallic compounds.

Sputtering: Sputtering is a coating and surface modification technique that occurs when an energetic particle impinges upon a material—either a solid or liquid. It can be used for a variety of applications: removing surface contaminants and barrier layers prior to film deposition, micromachining, etching, thinning, gettering, surface analysis, and thin film deposition. For thin film deposition, it provides the advantage of atomically cleaning surfaces *in situ*, thereby eliminating the need to transfer the cleaned substrates to another processing system. Sputtering can be used to produce functional coatings with a wide variety of properties, such as wear-resistant surfaces, corrosion-resistant layers, diffusion barriers, electrical conductance with controlled resistance, insulating properties, reflectivity, catalytic surfaces and good adhesion layers.

Technology Benefits and Advantages

- Can be used to either remove surface contaminants and/or apply coatings
- Reduces the use of hexavalent chromium, leading to reductions in environment, health and safety costs
- Reduces operator exposure to hexavalent chromium
- Reduces waste generation
- Improves wear life

Technology Limitations

- The IBAD system has higher equipment costs as compared to electroplating and other PVD processes. Extensive training is required for operators.
- Cathodic arc deposition and IBAD are line-of-sight processes and have surface area limitations.
- IBAD technology is in commercial infancy.
- With cathodic arc deposition, the possible occurrence of entrapment of the macroparticle inclusion in the growing film can result in nonhomogeneity in the microstructure and detrimental physical properties.

NDCEE FY01 & FY02 Accomplishments

- Produced a Demonstration Plan (FY01) that outlined the activities necessary to demonstrate each of the selected EHC alternatives, and the test methods and procedures used to evaluate the coatings and surface modifications. The alternatives had been identified in an FY00 Potential Alternatives Report for Ion Beam and Plasma-Based Alternatives to Chrome Plating of Gas Turbine Engine Parts.
- Demonstrated "next-generation" coatings/surface alternatives for DoD propulsion applications that offer the potential for dramatic improvements in the service life of original components, leading to longer service intervals and, hence, reduced use of chromium for repair processes. Depending on the PVD technology being demonstrated, a diamond-like carbon (DLC) coating chromium and tungsten carbide coating, tungsten carbide/carbide coating, chromium nitride (CrN) coating, and/or a CrN and niobium nitride super lattice coating were deposited on Inconel 718 nickel super alloy and 4340 steel substrates—the most prevalent materials in a gas turbine engine. The demonstrations were performed at vendor facilities (FY02).
- Performed corrosion, wear, adhesion and nanohardness tests on deposited coatings in accordance with the NDCEE Demonstration Plan to screen alternative coatings (FY02).

- Produced a Demonstration Report that documented the results of the demonstration/validation activities to determine the effectiveness of coatings produced via PVD methods (FY02). Based on the overall test results, DLC coatings that are deposited via PIIP performed better for wear resistance on 4340 steel, but were not tested at the highest loads on Inconel 718 because they are expected to degrade at the temperatures experienced in typical service applications. The titanium-implanted 4340 steel panels performed better than the other implants. CrN deposited via IBAD appears to be a good candidate for both 4340 steel and Inconel 718 substrates. Therefore, the DLC coatings are recommended for 4340 steel components only, and other coatings such as CrN produced via sputtering methods, showed potential on Inconel 718 substrates. Nevertheless, the NDCEE recommended that other variations of CrN, including those produced by sputtering and cathodic arc, and the DLC coatings, be studied more extensively in a separate follow-on program to obtain more statistically valid results.
- Produced a Justification Report that documented the technical justification of the alternatives recommended for further investigation as well as cost data that was representative of the types of alternatives recommended (FY02).
- Developing tantalum coatings (applied via sputtering) for gun barrel applications (FY02).
- Deposited hard nitride and oxide coatings using IBAD (FY01-FY02) in accordance with an on-going effort unrelated to the previously mentioned accomplishments. Coatings were deposited both on components and test coupons, on which either simulated service, field tests, or laboratory testing was performed.

Economic Analysis

In addition to the environmental concerns associated with EHC, issues related to long-term maintainability and reliability of DoD systems must be considered. Reductions in funding for national defense has necessitated continued operation of aging propulsion systems in aircraft, ships and certain military vehicles. Although EHC has been an accepted practice for many years for gas turbine engine repair, chromium is not necessarily the best material/process in terms of cost and mission effectiveness.

Each of the demonstrated PVD systems shows improved wear performance over EHC plating in coupon tests. This improvement is expected to increase part service life (i.e., the maintenance to rebuild worn parts, restore dimensional tolerance and replace a worn or damaged coating, such as hexavalent chromium, would occur less frequently). Extended service life can lead to a decrease in total cost-of-ownership through engine overhaul cycle and labor hours, and improved weapons system readiness. In addition, none of the investigated alternatives has to bear costs similar to the costs of waste disposal and regulatory compliance associated with hard chromium.

Suggested Implementation Applications

PVD technologies are particularly useful on parts that only use the bare substrate or for components that require a thin dense chrome coating.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Tasks

Pollution Prevention Initiative (Task N.227)
Sustainable Green Manufacturing (Tasks N.213 and N.301, Subtask R4-8)

Phytoaccumulation

The NDCEE used three types of plants to remove nonparticulate metals from soil. The demonstration test was performed on 3,500 tons of lead-contaminated soil from a small arms firing range. The NDCEE also demonstrated the feasibility of extracting heavy metal contaminants from the soil by recirculating the precipitation water that was captured in a lined phytoextraction cell through an onsite spray irrigation system.

Technology Description

Phytoaccumulation, also called phytoextraction or hyperaccumulation, refers to the use of metal- or salt-accumulating plants to translocate and concentrate suitable contaminants into the roots and above-ground shoots or leaves. Phytoaccumulation is a passive, *in-situ* phytotechnology that is an attractive alternative to conventional cleanup technologies due to its relatively low costs and inherently aesthetic nature of planted sites. As with other remediation technologies, however, this technology is appropriate only under certain conditions.

The phytoaccumulation treatment begins by conducting treatability studies to determine which plants are most amenable to contaminant and site conditions. Once the plants have been selected, they are planted and allowed to grow for several weeks or months before harvesting. After harvesting, the plants (biomass) are analyzed for total contaminant concentrations and undergo Toxicity Characteristic Leaching Procedure testing to determine if their tissue classifies as hazardous waste. Depending on the analytical results and the biomass quantities, the harvested plants may be landfilled, incinerated, or composted for disposal or sent to a smelter for recycling of the metals. Environmental regulators will play a role in determining the test method and requirements for ultimate disposition of the plant biomass. The planting and harvesting cycle may be repeated as necessary to lower soil contaminant levels to allowable limits.

DoD Need

Removal of non-particulate inorganics from soils

Army: R-4

Air Force: 567, 2502

Navy: 1.I.01.1, 1.I.04.j

For contaminants to be remediated using plants, they must come into contact with the plant roots. For an inorganic contaminant, this plant root contact is accomplished by dissolving the contaminant in the soil water that is then carried to the root zone and plant. As a general rule, readily amenable inorganic constituents for plant uptake include cadmium, nickel, zinc, arsenic, selenium and copper, while moderately amenable metals are cobalt, manganese and iron. Certain metals, such as lead, chromium and uranium, are not very amenable to plant uptake, but can be more so through the addition of certain materials to the soil. For example, lead can be made much more soluble by adding chelating agents, such as ethylene diamine tetra-acetic acid (EDTA), while the availability of uranium and radio-cesium 137 can be enhanced using citric acid and ammonium nitrate, respectively.

Use of plants to remove nonparticulate lead from range soils at Fort Dix.

Effective application of phytoaccumulation depends on the characteristics of the affected media (e.g., soil and groundwater), the constituents of concern and their concentration levels, the local climatic conditions and the site-specific remedial goals. These remediation goals may include stabilization, accumulation, reduction, degradation, metabolism, or mineralization of specific contaminants to reduce the associated risks to human health and the environment. Another goal may be containment to ensure that contaminants do not migrate offsite or impact other receptors. Vegetative groundcovers, tree hydraulic barriers and wetland plant systems can be used to control surface water and groundwater movement as well as to physically stabilize the soil environment (e.g., reduce erosion and dust emissions).

Technology Benefits and Advantages

- Is a low-maintenance, *in-situ*, passive, self-regulating, solar-driven system
- May be applicable for remote locations without utility access
- Decreases air and water emissions, as well as secondary waste streams, while improving aesthetics
- Controls soil erosion, infiltration, surface water runoff and fugitive dust emissions
- Remediates sites with multiple or mixed contaminants simultaneously
- Elicits favorable public perception, with increasing regulatory approval and standardization
- Sequesters carbon dioxide and greenhouse gases
- Improves worker health and safety because fewer field activities are conducted, less heavy equipment is used, and less noise is generated, with significantly reduced fugitive dust and other air emissions

Technology Limitations

- Water, RCRA and other permits may be needed.
- A thorough treatability study is required to determine whether phytoaccumulation is technically feasible and cost effective to reduce total heavy metal concentrations in the soil, based on site-specific soil conditions and contaminant levels.
- System design must be site specific, based on the type and distribution of contaminants, site physical and chemicals conditions, level of cleanup required, plants used, and applicable regulatory and policy issues.
- Plant roots must be in contact with the contaminated media to be effective.
- Phytoaccumulation is dependent on local climatic conditions.
- Removal rates are typically slower with phytotechnologies in comparison to other remediation technologies.
- Care must be taken to ensure that contaminants are not mobilized from the soil to the groundwater or from the soil/groundwater into the air.

NDCEE FY01 & FY02 Accomplishments

- Used three types of plants to remove lead from 3,589 tons of impact berm soils from SAFR 24, Fort Dix in a lined *ex-situ* phytoextraction cell (FY01).
- Developed and implemented a water management plan to control and dispose of excess water collected in the lined phytoextraction cell in an environmentally sound manner (FY01).
- Demonstrated the feasibility of extracting heavy metal contaminants from the impact berm soil by recirculating the precipitation water (containing nutrients and chelating agents) that was captured in the lined phytoextraction cell through the onsite spray irrigation system (FY01).
- Reconstructed the impact berm at SAFR 24 to meet Fort Dix requirements, dismantled the lined phytoextraction cell and water storage facilities, and demobilized from the site (FY02).
- Collected and analyzed soil, ground water, surface water and sediment samples from selected locations in the vicinity of SAFR 24 to document any changes in the quality of these environmental media that could be associated with the technology demonstrations (FY02).
- Prepared and submitted a Final Report to document the results of the demonstration/validation activities, including effectiveness of the particle separation technology to substantially reduce total soil lead concentrations; review and analysis of the operational difficulties encountered with

implementation of the phytoextraction technology; discussion of the lessons learned throughout the demonstration; cost analysis of the two technologies compared to baseline costs; and evaluation of environmental data (collected before and after the demonstrations) to meet state regulatory requirements, which indicated that the technology demonstrations did not adversely impact the environmental media in the vicinity of the range (FY02).

Economic Analysis

Phytoextraction costs will vary according to individual task requirements such as remedial goals, design of the phytoextraction cell, planting and harvesting cycles, and site-specific climatic conditions. Basic costs include treatability studies, mobilization and construction, soil sampling and analysis, irrigation system installation, planting and harvesting, utilities, and biomass disposal. Additional requirements, such as an impermeable liner underneath the cell, multiple phytoextraction phases, and water management facilities (storage pond and tanks) will increase costs. The number and extent of these phytoextraction elements can greatly impact project cost and duration, and thus, it is more useful to consider the range of unit costs for different phytoextraction scenarios rather than the unit cost range for a specific treatment scenario.

Low, medium and high cost estimates have been developed that correspond to three phytoextraction treatment scenarios that range from the simple to the complex. The three cost scenarios are based on a one-acre phytoextraction cell design that contains 1,613 cubic yards (2,178 tons) of contaminated soil and includes three different construction requirements and operational modes: (1) $23.87 per cubic yard ($17.68–$94.37 per ton) for single crop, verification sampling and low biomass disposal costs; (2) $70.37 per cubic yard ($52.13 per ton) for three crops, irrigation system, verification sampling and low biomass disposal costs; and (3) $127.40 per cubic yard ($94.37 per ton) for an impermeable liner underneath the cell, three crops, irrigation system, verification sampling, and high biomass disposal costs; with inclusion of excess water management costs (i.e., construction of a lined water storage pond and use of water storage tanks), this cost can increase to approximately $190 per cubic yard ($140 per ton).

While the lower-end phytoextraction unit cost is appealing, the potential for migration of mobilized or extracted lead, caused by the addition of chelating agents, is a concern that requires the use of a liner. Unless the results of site-specific contaminant fate and transport studies or additional phytoextraction projects negate the need for a liner, the cost for a liner system and the associated water management infrastructure must be incorporated into any phytoextraction project.

Suggested Implementation Applications

Any location with inorganic soil contamination is a candidate. According to the AERTA publication, 477 unique sites at 74 U.S. Army installations are from 9 MACOMs with confirmed inorganics soil contamination, and 80 unique sites of 17 Army installations from 4 MACOMs had suspected soil contamination. In addition, long-term monitoring of inorganics in soil was needed at 63 unique sites of 19 Army installations from 4 MACOMs.

Points of Contact

- Darlene Bader-Lohn, ODASA(ESOH), ACOR, (410) 436-6861, darlene.bader-lohn@aec.apgea.army.mil
- James Dawson, NDCEE, (303) 297-0180 x116, dawson@ctcgsc.org

Applicable NDCEE Task

Demonstration of RangeSafe System at Ft. Dix, NJ (Range 24) (Task N.204)

Piezoelectric Ceramic Fiber Composites

The NDCEE has assisted small- and medium-sized enterprises with commercializing their federally developed or supported technologies, which have both DoD and private-sector applications. For instance, the NDCEE helped Advanced Cerametrics, Inc. (ACI) with obtaining military and industrial commitments for its Piezoelectric Ceramic Fiber Composites.

Technology Description

Piezoelectric Ceramic Fiber Composites are flexible, conformable, and single- or multi-frequency piezoelectric materials that converts mechanical energy into electricity and electricity into mechanical energy. For example, the piezoelectric material can be placed in the sole of a shoe to capture the mechanical energy created by walking or running and convert that energy into electricity. The harvested electricity then could be used to generate heat, operate a cell phone, or, in the case of a soldier, power communications equipment, thus decreasing a soldier's reliance on batteries and reducing equipment weight.

The Piezoelectric ceramic fiber was developed for underwater listening applications for the Naval Underwater Warfare Center by ACI. ACI developed the technology with its own investment and with Small Business Innovation Research and other grants from the Office of Naval Research and Defense Advance Research Planning Agency. With assistance from the NDCEE team, other applications for the technology are being developed. For instance, the technology has been transferred into the top-of-the-line tennis racquet produced by HEAD brand sporting equipment. The assistance provided by the NDCEE team resulted in a $4.8 million contract between ACI and HEAD. In addition, ACI is working with Natick Soldier Center through a Cooperative Research and Development Agreement (CRADA) funded by the NDCEE Program to utilize the piezoelectric ceramic fiber for DoD energy-harvesting applications, such as in the Army's Land Warrior. The Land Warrior integrates small arms with high-tech equipment to enable ground forces to deploy, fight and win on the battlefields of the 21st Century.

Piezoelectric fiber composite technology addresses requirements outlined in Reducing the Logistics Burden for the Army After Next. The Military Critical Technology List notes a need for advanced mobile energy conservation and power generation technologies that reduce weight and volume, but increase reliability, performance and survivability. Soldiers of the future ideally will be their own power systems. As a result, power generation technology must be lightweight, compact and rugged. Piezoelectric fiber composite materials meet DoD needs for advanced energy systems because they are flexible, lightweight and can capture, store and release energy that would reduce and potentially eliminate the need for batteries.

DoD Need

Noise control, reusable energy, energy harvesting and acoustical devices

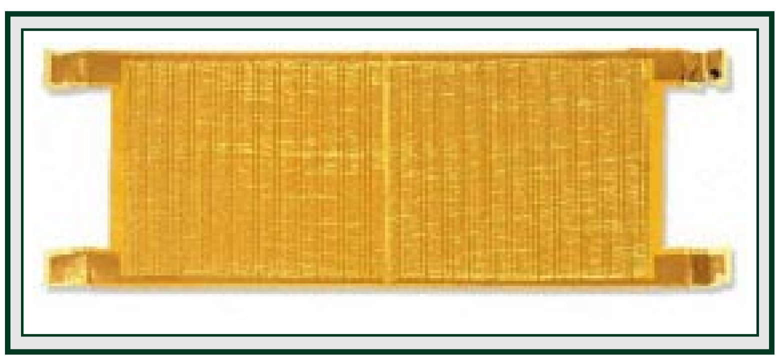
Army: CM-2

Air Force: 252

Navy: 2.IV.02.a, 2.IV.02.f

Technology Benefits and Advantages

- Converts mechanical energy into electricity and electricity into mechanical energy
- Is flexible, conformable and low-cost in comparison to many other materials
- Has wide-ranging applications in defense and commercial sectors in areas such as energy creation, medical treatment, acoustical or sonar devices and sensing markets



Piezoelectric ceramic fiber composites

Technology Limitations

- Serves only small energy requirements (275 Volts at 4.2 milliWatts per footstep), but development work is focusing on improving this limitation. The stated goal of the CRADA is 275 volts at 10 milliWatts.

NDCEE FY01 & FY02 Accomplishments

- Assisted ACI with signing a CRADA with the Natick Soldier Center (FY01).
- Assisted with negotiation of a commercial contract in FY00. As a result of this contract, in FY01, the cost of fibers decreased by over 90%, which is greatly benefiting federal procurements of the fibers.
- Assisted with creating a request for Pre-Commercialization Funds (FY01). These monies were used to fund the co-development of the ceramic for energy harvesting for the foot soldier.
- Transitioned the technology to the FY02 project for further commercialization (FY01).

Economic Analysis

The commercialization of these fibers in the sporting goods market has contributed greatly to the reduction of the cost of these fibers for all markets, including DoD. On the cheaper fiber, ACI has reduced its cost of manufacture to $1.50 per unit from $70 per unit. On the more expensive fiber, ACI has reduced the cost of manufacture to $20 per unit from $250 per unit, rapidly approaching the break-even point and profitability. When the effort began, ACI was manufacturing 1 kilogram of fiber per week; the company is now manufacturing between 10–15 kilograms per day.

Suggested Implementation Applications

The technology has applications in the medical, defense, energy harvesting, apparel, recreation, acoustical device and sensing industries. Defense applications include self-powering fiber patches for sonar devices that produce higher quality sound and less ambient noise; fiber for devices and equipment that capture, store and release energy; and fiber applied to helicopter rotors that would reduce noise, friction and wear and increase fuel range.

Applications outside the military include ultrasound imaging and bone healing for the medical industry, vibration reduction and reusable energy in sporting equipment and other apparel, and acoustical devices for music and voice reproduction and amplification.

Points of Contact

- Hany Zaghloul, CERL, (217) 373-3433, Hany.Zaghloul@hqda.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, gary.grimm@daapgea050.apgea.army.mil
- William Tumblin, II, NDCEE, (864) 271-8218, tumblin@ctcgsc.org

Applicable NDCEE Task

Commercialization of Technologies to Lower Defense Costs (Task N.224)

Plasma-Assisted Chemical Vapor Deposition

The NDCEE has demonstrated and evaluated the feasibility of using Plasma-Assisted Chemical Vapor Deposition (PACVD) to deposit diamond-like carbon (DLC) coatings on Inconel 718 and 4340 steel substrates. The NDCEE has determined that the process could be a viable surface protection replacement for EHC in terms of wear resistance on 4340 steel, but additional testing is recommended prior to implementation by a DoD repair facility. Because DLC coatings are expected to degrade at the temperatures experienced in service by the components made for Inconel 718, the NDCEE does not recommend it for that substrate material.

Technology Description

PACVD is a surface protection technique that combines the good adhesion properties of chemical vapor deposition with the low temperatures of plasma vapor deposition while avoiding their typical drawbacks (high temperature with deformation and poor adhesion). PACVD is used for the application of thin film coatings and particularly for the deposition of diamond films.

For DLC coatings, PACVD uses microwaves or an electric field inside a vacuum chamber to create plasma. After the creation of the plasma, carbon is introduced into the chamber. The carbon electrons collide with plasma ions. Energetic bombardment occurs in which an instantaneous local high temperature and pressure induce a proportion of the carbon atoms to bond in a diamond-like chemical structure. Components to be coated are placed on an electrode, which is 'capacitively' coupled to a radio frequency (RF) source. Temperatures are lowered to 400–600^{o}F (204–315^{o}C), limiting deformations. In a cleaning stage, an inert gas, such as argon, is introduced. The argon is ionized by the RF field, and the positive ions bombard and clean the substrates. The cleaning stage is followed by the deposition stage in which a carbon-containing gas, such as acetylene, is introduced to provide the energetic carbon ions.

PACVD equipment consists of two units. The first unit contains the electronic controls, and the second unit contains a vacuum chamber, pumps, gas flow controllers and RF matching unit. Up to four gases can be introduced. The system may be operated in manual, semi-manual or fully automatic mode.

Technology Benefits and Advantages

- Produces a coating with a low-friction and low-adhesion surface
- Improves safety and worker health conditions due to the reduction or elimination of hexavalent chromium
- Reduces the operational costs and labor requirements as a result of eliminating hazardous materials and the associated compliance procedures/processes
- Reduces waste generation
- Extends wear life of original components and reduces maintenance costs

Technology Limitations

- High capital costs
- Extensive training required for operators
- Line-of-sight limitations
- Limitations of surface area that can be treated

NDCEE FY01 & FY02 Accomplishments

- Produced a Demonstration Plan (FY01) that outlined the activities necessary to demonstrate selected EHC alternatives, including PACVD, and the test methods and procedures that are used to evaluate the coatings and surface modifications. The

DoD Need

Surface protection and corrosion control

Army: P2-6

Navy: 2.I.01.g, 3.I.03.e, 3.I.04.h

Air Force: 613, 805

alternatives had been identified in an FY00 Potential Alternatives Report for Ion Beam and Plasma-Based Alternatives to Chrome Plating of Gas Turbine Engine Parts.

- Demonstrated the feasibility of using PACVD to deposit a DLC coating for DoD propulsion applications (FY02). The demonstration was performed at a vendor facility.
- Performed corrosion, wear, adhesion and nanohardness tests on deposits in accordance with the NDCEE Demonstration Plan to screen alternative coatings (FY02).
- Produced a Demonstration Report that documented the results of the demonstration/validation activities to determine the effectiveness of PACVD (FY02). Based on the overall test results, DLC coatings that are deposited via PACVD performed better in terms of wear resistance on 4340 steel than EHC. However, the steel panels were not tested at the highest loads on IN718 because they are expected to degrade at the temperatures that IN718 components often experience in service.
- Produced Justification Report that documented the technical justification for recommending PACVD for further investigation (FY02). A Final Report was also produced that summarized the activities associated with evaluating EHC alternatives (FY02).

Economic Analysis

In addition to the environmental concerns associated with EHC, issues related to long-term maintainability and reliability of DoD systems must be considered. Reductions in funding for national defense has necessitated continued operation of aging propulsion systems in aircraft, ships, and certain military vehicles. Although chromium plating has been an accepted practice for many years for gas turbine engine repair, chromium is not necessarily the best material/process in terms of cost and mission effectiveness.

PACVD showed improved wear performance over EHC in coupon tests. This improvement is expected to increase part service life, which includes the maintenance to rebuild worn parts, restore dimensional tolerance, and replace a worn or damaged coating such as hexavalent chromium would occur less frequently. Extended service life can lead to a decrease in total cost-of-ownership through engine overhaul cycle and labor hours and improved weapons system readiness. In addition, this alternative should have lower waste disposal and regulatory compliance costs than those associated with hard chromium.

Suggested Implementation Applications

PACVD is used for many mechanical-tribological applications where parts, such as those found in engines, require a low coefficient of friction and high wear resistance. PAVCD-applied DLC coatings also are commonly used in medical devices as well as electronics. DLC coatings can be applied to a wide range of metals, ceramics, glasses and plastics.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Plastic Media Blasting

The NDCEE has demonstrated and evaluated the feasibility of using an automated or semiautomated Plastic Media Blasting (PMB) system at Ogden Air Logistics Center. This system will replace the use of methylene chloride immersion, which Ogden ALC currently uses to remove coatings from landing gear wheels and components.

Technology Description

PMB is a dry abrasive blasting process that is designed to replace conventional sand blasting and chemical paint stripping operations. It is performed in a ventilated enclosure such as a walk-in booth, small cabinet (glove box), large room or airplane hanger. The blast media are soft, angular plastic particles that are blasted at a much lower pressure (less than 40 psi) than conventional blasting. PMB is well suited for stripping paints because the low pressure and relatively soft plastic medium have little, if any, effect on the surfaces under the paint. PMB also has been proven more efficient than chemical paint removal.

After usage, the blast media enter a reclamation system that consists of a cyclone centrifuge, a dual-adjustable air wash, multiple vibrating classifier screen decks, a dense particle separator and a magnetic separator. This system separates the denser particles (e.g., paint chips, sand, grit and aged sealant particles) from the reusable blast media. The denser particles are disposed of, and the reusable media is returned to the blast pot. Media usually can be recycled 10–12 times before becoming too small to remove paint effectively.

Manufactured in seven types, plastic media are available in a variety of sizes and hardnesses. PMB usage is governed by military specification MIL-P-85891, which provides general information on the types and characteristics of plastic media. The plastic blasting media types are:

- Type I Polyester (Thermoset)
- Type II Urea formaldehyde (Thermoset)
- Type III Melamine formaldehyde (Thermoset)
- Type IV Phenol formaldehyde (Thermoset)
- Type V Acrylic (Thermoplastic)
- Type VI Poly (allyl diglycol carbonate) (Thermoset)
- Type VII Starch-g-acrylic.

PMB facilities typically use one type of plastic media for all of their PMB work, with most DoD PMB facilities using either Type II or Type V media. Type II is better for steel-only surfaces. Type V media is more commonly used on aircraft because it is not as hard as Type II media and is gentler on delicate substrates.

DoD Need

Environmentally compliant paint stripping method

Army: CM-3, CM-9, P2-1

Air Force: 814, 988, 1232, 120, 225, 311, 1468

Navy: 3.I.05.a

Plastic Media Blasting can replace the use of methylene chloride immersion, which is often used to remove coatings from landing gear wheels and components.

Technology Benefits and Advantages

- Recycled media (10–12 recycling events), which generates less hazardous waste volume than traditional sand blasting operations
- Improved safety and worker health conditions since it eliminates solvents contained in chemical paint stripping operations
- Realized cost savings in labor, materials, handling and disposal of waste, particularly when compared to chemical paint stripping

Technology Limitations

- As with any blasting operation, airborne dust is a major safety and health concern. Proper precautions should be taken to ensure that personnel do not inhale dust/ particulate matter.
- Substantial capital equipment investment is required.
- Quality of stripping is dependent on skill and experience level of the operator.
- The system may not remove corrosion products.
- Military specifications do not permit PMB for depainting certain types of materials.
- While PMB waste may be exempt from Resource Conservation and Recovery Act regulation as a hazardous waste, it may be classified as a hazardous material due to the presence of metals for transportation purposes. An alternative disposal solution is to contact a vendor who will "lease" the blast media to the facility and then use the waste media in the manufacturing process for consumer products such as bathroom sinks and plastic yard pots and benches.

NDCEE FY01 & FY02 Accomplishments

- Conducted a site visit at Ogden ALC to establish a baseline for current processes to perform a Requirements Analysis (FY02).
- Produced a Quality Assurance/Quality Control Plan as well as a Test Plan (FY02).
- Demonstrated the PMB technology by selecting, identifying and evaluating candidates (FY02). In FY03, additional coatings removal alternatives will be evaluated against Ogden ALC's current process and PMB. Based on the evaluation findings, demonstrations of these technologies will be performed.

Economic Analysis

PMB systems can range in cost from $7,000 for a small portable unit to $1,400,000 for a major facility for aircraft stripping.

Suggested Implementation Applications

PMB is in use throughout the U.S. Air Force, Army and Navy. Plastic media glove boxes and enclosed blasting booths have been installed at depot and intermediate level aircraft maintenance activities to remove paint from support equipment and components (such as landing gear wheels). A blast media lease and recycle program is currently in place at many facilities.

Points of Contact

- Brad Christiensen, Hill AFB, (801) 777-3188, Bradley.Christensen@HILL.af.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Michael Docherty, NDCEE, (814) 269-6462, docherty@ctcgsc.org

Applicable NDCEE Task

Automated Plastic Media Blast for Depainting Landing Gear Wheels for Commodities Directorate Ogden Air Logistics Center (Task N.258)

Powder Coating

The NDCEE has extensive technical expertise with Powder Coating. The technology is an integral aspect of the NDCEE Demonstration Facility where it has been used for nearly a decade by DoD and industrial facilities to explore the technology's viability for their site-specific needs. Once the technology has been validated to be technically and economically beneficial for a facility, the NDCEE provides implementation and training assistance to the facility. Most recent beneficiaries of NDCEE Powder Coating knowledge have been Tobyhanna Army Depot, Rock Island Arsenal, and Lake City Army Ammunition Plant. Past recipients have included Naval Air Depot - Jacksonville and the Joint Group on Pollution Prevention.

Technology Description

Powder Coating technology is an environmentally friendly alternative to the use of conventional solvent-based, waterborne, or high-solids painting processes. It provides a durable coating and reduces operating costs while eliminating hazardous air pollutants, volatile organic compounds, and solvents. The four basic Powder Coating application methods are electrostatic spraying, flame spray, fluidized bed, and electrostatic fluidized bed. Electrostatic spraying is the most frequently used method. For all four methods, surface preparation (i.e., cleaning and conversion coating) is required to develop a good coating adhesion substrate. Characteristics of each method are described below.

In *electrostatic spraying*, an electrical charge is applied to the dry powder particles while the component to be coated is electrically grounded. The charged powder and grounded workpiece create an electrostatic field that attracts and holds the paint particles to the workpiece. The coated workpiece is placed in a curing oven where the paint particles are melted onto the surface, fused and cured.

The *flame-spray* technique was developed primarily for application of thermoplastic powder coatings. After being fluidized by compressed air, the thermoplastic powder is fed into a flame gun where it is injected through a flame of propane, melting the powder. The molten coating then is deposited on the workpiece, forming a film on solidification. Because no direct heating of the workpiece is required, this technique is suitable for applying coatings to most substrates, including metal, wood, rubber and masonry. It also is useful for coating large or permanently fixed objects.

In a *fluidized bed*, an air stream keeps powder particles in suspension until they come in contact with a preheated workpiece, at which point, they melt and adhere to the workpiece surface. Coating thickness is dependent on the temperature and heat capacity of the workpiece and its residence time in the bed. Typically, post heating is not required to cure thermoplastic powder coatings, but it is required to cure thermoset powder coatings completely.

With *electrostatic fluidized beds*, the air stream is electrically charged as it enters the bed. The ionized air then charges the powder particles, which cover the grounded workpiece as it enters the chamber. Unlike with the conventional fluidized bed, this technique does not require a preheated workpiece, but curing of the coating is necessary. This technology is most suitable for coating small objects with simple geometry.

Powder coatings are individually formulated to meet specific finishing needs (e.g., desired properties) and fall into two basic categories: thermoplastic and thermosetting. Generally, thermoplastic powders use epoxy, polyester and acrylic resins and

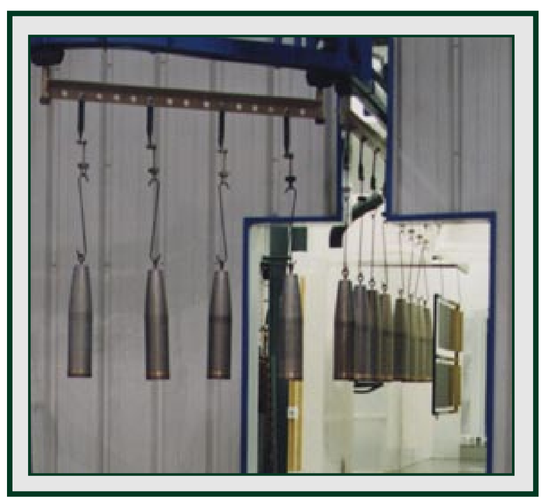
DoD Need

Environmentally compliant coating system

Army: CM-3, P2-1

Air Force: 1261

Navy: 2.1.01.g, 2.1.01.q, 3.I.04.h



Automated powder application to 105-millimeter artillery projectiles.

are more suitable for thicker coatings, providing increased durability. Thermosetting powders are often used when comparatively thin coatings are desired, such as decorative coatings. They primarily contain polyethylene, polyvinyl, nylon and fluoropolymer resins.

In comparison to conventional painting techniques, Powder Coating provides improved safety and working conditions as well as cost savings in labor, materials, handling and disposal of waste. It eliminates most waste streams, such as spent cleaning solvents, air emissions, and waste streams generated from air emission control equipment. Cleanup time is faster because the powder is dry when sprayed, allowing overspray to be readily retrieved and recycled for reuse. Consequently, powder usage efficiency can approach 100% because the overspray powder is separated from the air stream by various vacuum and filtering methods and returned to a feed hopper for reuse.

Technology Benefits and Advantages

- Eliminates the use of VOCs and HAPs used as solvents in paints and thereby eliminates hazardous air emissions
- Improves worker health and safety risks
- Can be implemented in high-production facilities with highly automated application systems or on low-volume, manual-batch applications
- Usage efficiencies approach 100% because overspray can be captured and recycled
- Reduces energy requirements resulting from recirculation of spray booth air to remote emissions
- Realizes cost savings in labor, materials, and handling and disposal of waste

Technology Limitations

- As with other coatings, the booth environment must be controlled to eliminate explosion hazards (accumulation of suspended particulate). Powder and air mixtures can be a fire hazard when an ignition source is introduced.
- System configurations are partially application-specific, but not severely limited.
- Depending on the system, some application limitations may apply such as intricate shapes and assembled components.
- Only workpieces that can be oven-heated are suitable for Powder Coating application methods. The temperatures that are required to cure the coating are too high for many materials used in aerospace structures (primarily aluminum); however, recently developed formulations allow baking as low as 250°F (121°C), which enables the use of Powder Coating on most materials.
- If primers or pretreatments are not used, the Powder Coating provides protection as a barrier and prevents corrosion only as long as it is intact and undamaged.

NDCEE FY01 & FY02 Accomplishments

- Produced an interim Performance and Cost Analysis Report for LCAAP in which Powder Coating was determined to be a technically feasible replacement for the current wet spray application method at LCAAP (FY01). However, the NDCEE found that material handling and masking issues must be addressed prior to implementing powder coating into LCAAP for painting of projectile tips. In addition, for economic reasons, the NDCEE recommended that other environmentally acceptable painting technologies, such as UV-curable liquids, should be explored.
- Conducted additional Powder Coating demonstration/validation activities at LCAAP and the NDCEE Demonstration Facility to evaluate larger-scale issues such as Powder Coating build-up on bullet tips and improving application to ensure

that Powder Coating fits the high-speed production requirements of the U.S. Army (FY02). A trial coating of 20,000 tracer projectiles was performed, with the projectiles then being sent for assembly and test firing trials. All trials were successful and LCAAP personnel liked the quality and adhesion of the powder coating.

- Qualified and validated Powder Coating as an alternative to the solvent-based primer/topcoat system used on internal components processed at RIA (FY02).
- Completed initial demonstration/validation activities for TYAD (FY02). Based on demonstration results, TYAD approved of the implementation of 24533 green powder.
- Efforts are in progress to test and evaluate two additional colors for TYAD (FY02–FY03). Upon conclusion of the evaluation and assuming successful findings, the NDCEE will help to design, purchase, and implement a Powder Coating system at TYAD. As part of the implementation process, the NDCEE will conduct a cost-benefit analysis to ensure implementing the Powder Coating technology would be a sound fiscal decision.

Economic Analysis

The typical capital costs for a Powder Coating system can range from $20,000 to greater than $4 million. The NDCEE performed a cost analysis to determine the maximum capital expenditure that would be allowable for LCAAP to stay within a three-year payback period. For that payback period, the equipment, installation and facility modification costs must be no more than $360,000, which is much less than the cost of a typical Powder Coating installation. The 15-year value was calculated to be $396,111 and the internal rate of return was 54%.

Suggested Implementation Applications

Powder coatings are commonly used on a wide assortment of products from bullets to park benches to automobiles. To ensure that Powder Coating is their best coating option, DoD paint facilities should conduct a technical and economic evaluation prior to implementation.

Points of Contact

- Joe Argento, Industrial Ecology Center, (973) 724-2428, argento@pica.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- David Schario, NDCEE, (814) 269-6465, schario@ctcgsc.org

Applicable NDCEE Tasks

Evaluation of Powder Coating Technology for Small-Arms Bullet Tip Identification (Task N.212)
Sustainable Green Manufacturing (Task N.213), Subtask R4-8
Powder Coating of Ammunition Components (Task N.248)
Sustainable Green Manufacturing (Task N.301), Subtask R3-8

Pulsed High-Voltage Aluminum Ion Vapor Deposition Process

The NDCEE has demonstrated and evaluated the feasibility of using a Pulsed High-Voltage Aluminum Ion Vapor Deposition (IVD) Process. DoD repair depots commonly use IVD to provide surface protection of components.

Technology Description

Conventional ion vapor deposition is used to apply sacrificial aluminum coatings on metallic parts as an alternative to zinc or cadmium plating. The IVD process is performed in a chamber that is evacuated to a pressure in the 10^{-5} Torr range by a series of vacuum pumps. During the process, the aluminum is vaporized using resistive methods and the parts are biased negatively, which attracts ionized coating material as well as ions from the gaseous plasma towards the parts.

After deposition, the coating is glass-bead peened to test adhesion and provide an even denser surface for improved corrosion protection. The parts are then immersed into a chromate conversion coating solution and rinsed in hot water. The treatment imparts greater corrosion resistance and lubricity and provides a surface amenable to painting.

DoD Need

Surface protection and control

Army: P2-6

Navy: 3.I.03.e, 3.I.04.h

Air Force: 805

ISM Technologies, a division of Cutting Edge Products, Inc., in conjunction with the former McDonnell Douglas Aerospace (now part of the Boeing Company) developed an improved IVD aluminum process as an alternative coating system to minimize the need for large capital investments in new systems while reducing environmental impact and production costs. The process is implemented by retrofitting existing IVD aluminum chambers with a pulsed high-voltage (10 kilovolt) power supply. The pulsed high-voltage bias is applied to parts. Because the bias is greater than in conventional IVD, the ions are attracted and accelerated at greater velocities. Therefore, more momentum is transferred to the depositing coating, resulting in the collapsing of coating voids, which theoretically leads to a denser aluminum coating. In tests performed by ISM Technologies, the resulting IVD coating, when combined with conventional chromating processes, showed significant improvement in corrosion resistance over conventional chromated IVD deposits when a 1-mil aluminum coating was applied. Because chromate solutions use hexavalent chromium, a class one human carcinogen, nonchromate processes are being evaluated with the new IVD process, with and without the glass-bead peening process.

The Pulsed High-Voltage Aluminum IVD Process may help to reduce corrosion on DoD weapons systems.

Technology Benefits and Advantages

- Causes no reduction in product quality or part throughput in comparison to present processes

- Reduces material and operating costs because glass-bead peening is eliminated and less hazardous waste is generated/disposed
- Reduces worker health and safety risks by eliminating the use of hexavalent chromium
- Can be retrofitted onto existing IVD processes, thereby, avoiding large capital investment costs

Technology Limitations

- As with conventional IVD processes, technology has line-of-sight limitations.

NDCEE FY01 & FY02 Accomplishments

- Conducted a demonstration on the Pulsed High-Voltage Aluminum IVD Process using five nonchromate coatings: Alodine 2600 by Henkel Surface Technologies, 168 and 605 Processes by Natural Coating Systems, Full Process by Sanchem, Inc., and a trivalent chromium pretreatment (TCP) developed by NAVAIR (FY02).
- Produced a Demonstration Report that detailed the demonstration results (FY02). Demonstration data provided contradictory evidence, with two studies suggesting that the improved IVD process provided better corrosion protection and one favoring the conventional process. The only consistent trend was that NAVAIR's TCP with color provided adequate corrosion protection, with and without peening. Based on these findings, additional work is required to further optimize the process to produce coated test panels with repeatable results.
- Produced a Justification Report that documented the findings of a cost-benefit analysis for using conventional IVD (with and without glass-bead peening) with a nonchromate treatment (FY02). Baseline costs were obtained from Oklahoma City Air Logistics Center.

Economic Analysis

Because the pulse IVD did not show a performance improvement, an ECAM^{SM} analysis was not performed on the technology. However, the NDCEE conducted an economic analysis to measure the financial feasibility of implementing the TCP conversion coating in conjunction with a conventional IVD process. The analysis revealed that use of conventional IVD followed by TCP is effective at offering improved corrosion protection at OC-ALC. The analysis also indicated that overall operating costs would remain the same if glass-bead peening was used with TCP. The finding suggests that other DoD repair depots using IVD aluminum coatings should obtain similar results.

Other nonquantifiable benefits also were identified that favor implementation. These benefits include the elimination of worker exposure to the carcinogen, increased ability (and possible reduced costs) to meeting present or future OSHA exposure limits for hexavalent chromium, reduced shipping and storage hazards and simplified requirements for treatment of the process wastewater.

Suggested Implementation Applications

Any location with conventional IVD systems would be a potential implemenation site. Applicable weapon systems include M-80, M60, M48 (ANAD); CH 60, F-15, F-18 (NADEP-JAX); and B52H, C141, E3, KC135, C18, E8 (OC-ALC).

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227)

Remote Acoustic Impact Doppler

The NDCEE has assisted small- and medium-sized enterprises with commercializing their federally developed or supported technologies, which have both DoD and private-sector applications. For instance, the NDCEE helped Holographics, Inc., the technology developer of the Remote Acoustic Impact Doppler (RAID), raise $1.7 million in two separate rounds of equity financing. It also assisted in negotiating a strategic partnership between Holographics and Advanced Power Technologies Inc. (APTI) to develop RAID for aviation applications. Through the United Kingdom-based company, BBA Diagnostics, LLC, (a joint venture between BBA Aviation, and Advanced Power Technologies, Inc.) funding is now available for the first full installation of a fully robotic RAID system to inspect executive jet aircraft.

Technology Description

The RAID uses an optical vibration measurement system to detect delamination, cracking and other faults in metals and composite structures, such as aircraft, holding tanks and vessel hulls. The robotic system can describe and locate damage in an extremely straightforward manner.

RAID is a new concept in nondestructive techniques (NDTs) based upon the production of a very brief, high-energy acoustic impulse remotely air coupled from a distance of up to 12 feet. It was designed to detect and image hidden flaws below the surface of many materials such as debonds in layered materials and corrosion in metal structures. The acoustic impulse, produced by a patented acoustic transducer, is an actual wave that impacts the surface of the object undergoing testing in a manner somewhat analogous to that which is employed in the well known “tap test.” This impulse excites out-of-plane vibrations in the test object (relaxation frequencies) that are directly related to the subsurface situation immediately below the area being interrogated. Holographics has devised an algorithm and developed software to automatically analyze the frequency bands for defect information. Because RAID retains a rich data set, various signal-processing algorithms can be applied to characterize and quantify defect indications. The NDT result is presented in the form of a video image of the object with a colored graphical overlay of all damage spots and substructures. This presentation makes interpretation and damage location extremely straightforward.

DoD Need

Reduce aircraft downtime due to extensive maintenance that may not be necessary

The heart of the Holographics noncontacting RAID system is a proprietary design acoustic transducer that produces an air-coupled shock wave. This wave is achieved by discharging a high-voltage capacitor within a period of less than five microseconds. The RAID system is designed to take advantage of the underlying physics of the tap test while significantly improving sensitivity and deployment issues. The technology will directly image flaws, which has not been the case with many similar technologies in the past.

The technology encompasses seven of the current NDTs and research and development trends into a single technique. These trends are Quantification (Enhanced Visual), Automation of Image Interpretation (Enhanced Visual), More Sophisticated Signal and Data Processing (Eddy Current), More Efficient Scanning Methods (Ultrasonics), Air Coupling (Laser Ultrasonics), Time Domain Analysis (Thermogragphy), and Color Coding and 3-D Output (to Support Data Fusion).

Technology Benefits and Advantages

- Detects imperfections or failures in various structures, particularly aircraft and piping systems
- Reduces capital and maintenance costs by helping to extend the life span of malfunctioning equipment that was previously replaced rather than fixed

- Reduces aircraft downtime due to extensive maintenance that may not be necessary
- Reduces labor costs because it is a fully robotic system
- Provides economic and environmental benefits to the military, as well as oil, gas and other industries, by preventing failures and spills
- Detects defects, including corrosion, better than other NDTs

Technology Limitations

- The sparking transducer could cause an explosion hazard.
- The electrical and acoustic noise that is produced by the transducer could limit applications.

Economic Analysis

The U.S. military spends millions of dollars every year on aircraft examinations, and commercial airlines face inspections every 4–5 years at an approximate cost of $2 million per plane. New, more efficient methods of NDTs are actively pursued to decrease these costs and examination time. The primary benefit to the U.S. Air Force, where most of the work has been done to date, is in the reduction of maintenance costs through earlier detection of defects, including corrosion. Claims include a less expensive, quicker and more reliable method to inspect military and commercial aircraft especially those having composite components within the inspection. One key feature is the remote noncontacting operation of the system. Data presentation, damage tracking and archiving are other important features of the RAID system.

NDCEE FY01 & FY02 Accomplishments

The NDCEE commercialization effort included submission of a major proposal to the Air Force for E-3 AWACS rotodome inspection. RAID was chosen over laser ultrasound as the basis for a fully automated aerospace inspection system (FY01). The technology candidate was transitioned to the FY02 effort where it is expected that the robotics platform for RAID will be completed in late FY02.

Suggested Implementation Applications

The RAID technology could be used at any site that must monitor the structural integrity of its metals and composite structures such as aircraft, holding tanks and vessel hulls.

Points of Contact

- Hany Zaghloul, CERL, (217) 373-3433, Hany.Zaghloul@hqda.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, gary.grimm@daapgea050.apgea.army.mil
- William Tumblin, II, NDCEE, (864) 271-8218, tumblin@ctcgsc.org

Applicable NDCEE Task

Commercialization of Technologies to Lower Defense Costs (Task N.224)

Reverse Osmosis Water Purification System

The NDCEE has extensive expertise with water purification technologies, several of which are housed in the NDCEE Demonstration Facility. Recently, at the request of Anniston Army Depot, the NDCEE identified a reverse osmosis (RO)/ion exchange system as the best solution for eliminating mineral deposition associated with ANAD's chrome plating process. The NDCEE recommended this water conditioning solution after extensive market research was conducted and based on a technical, operational and financial analysis of several potential solutions.

Technology Description

The Reverse Osmosis Water Purification System uses a semipermeable membrane to separate pure water from dissolved solutes (i.e., salts and organics such as sugar or dissolved oils). Osmotic theory states that when a contaminated liquid is separated from pure water by a semipermeable membrane, the higher osmotic pressure of the contaminated liquid causes the water to diffuse into the contaminated solution. Water will continue to permeate into the contaminated solution until the osmotic pressure of the contaminated liquid equals the pure water. RO occurs when an external pressure is exerted on the contaminated liquid. In this case, water flows in the reverse direction from the contaminated solution into pure water.

The RO process is applicable for particles in the ionic range of less than 1 micron. It is often used in tandem with an efficient particle filter, such as an ultrafiltration (UF), which removes most of the relatively large constituents of a process stream before an RO application selectively removes water from the remaining mixture.

UF-RO modules are skid mounted and consist of a tank and high-pressure feed system. The feed system includes a centrifugal feed pump, a prefilter cartridge housing, and a triplex plunger pump. The processing units are self-contained and need only electrical and interconnection process piping to operate.

ANAD is using an RO system in conjunction with a small ion exchange unit to supply mineral-reduced water for its chrome plating process. The plating process currently requires the use of two multistage demisters to prevent the release of hexavalent chromium emissions. The chromium demisters use municipal tap water, which has a high mineral content. Prior to implementation of the RO/ion exchange system, the minerals clogged the filter mesh pads inside the demisters, resulting in high operational costs, unnecessary down time, and the potential of producing noncompliant high-pressure drop readings across the pads and reduced water flow.

DoD Need

Improved treatment of effluent discharges

Army: CM-5, CM-7, CM-10

Navy: 2.II.01.q, 3.I.03.b, 3.I.11.b, 3.I.11.j, 3.I.13.a

Reverse Osmosis Purification System

Technology Benefits and Advantages

- Applicable to a variety of liquid waste streams
- Suitable for use at sea

Technology Limitations

- Many membranes are susceptible to attack by free chlorine or other oxidizers in the feed water.

- Thin film composite membranes (typically a polyamide membrane on a support such as polysulfone) disintegrate as they oxidize feed water. They generally last up to 1,000 parts per million-hours of exposure times the concentration of the oxidizer (such as chromate or chlorine). The term "1,000 parts per million-hours" means that if 100 parts per million of chlorine was fed through the RO, the membrane would last 10 hours; and if 1 parts per million of chlorine was fed through the RO, the membrane would last 1,000 hours.
- If iron or sulfur is present in the feed water and the water is in an oxidizing state, iron (III) or elemental sulfur may be precipitated onto the membrane surfaces. Both compounds are nearly impossible to remove from membranes once they are deposited.

NDCEE FY01 & FY02 Accomplishments

- Evaluated and assessed various water-conditioning systems that were in accordance with ANAD's requirements. Findings were documented in an Alternatives Report (FY01).
- Conducted a cost-benefit analysis that was documented in a Justification Report (FY01).
- Installed and implemented an RO at ANAD. The RO process, in conjunction with an ion exchange unit, was selected as the technology best capable of preventing mineral deposits from clogging the demister filter pads. Findings revealed that ANAD's plating process efficiency would significantly improve with the RO/ exchange unit by minimizing operational down time and costs associated with demister pad cleaning (FY01).
- Produced an Installation Report (including training materials) documenting the installation process at ANAD (FY01).
- Provided onsite equipment operation and maintenance training for ANAD personnel (FY01).

Economic Analysis

In a cost-benefit analysis for ANAD, the NDCEE estimated that the implementation and use of the system would require an initial capital investment of approximately $19,000 and yield a payback period of approximately one year and a 93% return on investment. Projected annual operational costs are negligible in comparison to the current annual operational cost of $58,000.

Suggested Implementation Applications

RO continues to be a growing technology that has many potential applications to purify water and wastewaters. Facilities with wastewater issues should first perform a technical and financial evaluation on the application prior to purchase and implementation.

Points of Contact

- John Larkins, U.S. Army, (256) 235.7189
- Albert Walker, ODASA(ESOH), (410) 436-6867, Albert.Walker@daapgea050.apgea.army.mil
- John Millemaci, NDCEE, (904) 722-2519, millemaj@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Investigation for Chromium Demister at Anniston Army Depot (Task N.261)

Sludge Drying System for Industrial Wastewater

In August 2002, the NDCEE installed a sludge dryer as an addition to an existing filter press in the new Industrial Operations Facility at Tobyhanna Army Depot. Currently, the solids from the microfilter (hazardous metal sulfide waste) are collected and sent to a conical-bottom thickener tank and then directly to a filter press. Prior to use of the sludge dryer, the semi-dry sludge contained in the filter press would be dropped into two pans (approximately 4' x 4' x 1' deep) located on the floor. The heavy pans would then be emptied into 55-gallon hazardous waste drums. In addition to being labor-intensive, the handling process had the potential to contaminate the floor with sludge.

Technology Description

A sludge drying system (dehydrator) is commonly used within industrial wastewater treatment facilities to reduce the volume and weight of solids disposal. The dryer is used in conjunction with a filter press to efficiently dewater filter press cake for handling as dried particulates. The following description applies to the refurbished, natural gas fired dryer (JWI Model 180G) installed at TYAD. This dryer is capable of removing 94 pounds of water from 3 cubic feet of sludge per hour. The estimated sludge-processing rate is 3 cubic feet per hour.

Filter cake from an existing filter press drops into the hopper of the sludge dryer. Bridge breakers in the dryer's receiver hopper break the filter cake for feeding into the dryer's extruder system, which forms the particles into pellets with maximum surface area for drying. The extruded material falls onto the continuous stainless steel mesh conveyor for passage under a series of highly efficient infrared heat drying elements. The heating energy is from natural gas-fired burners. Ambient air is drawn through the heat chamber by the fan mounted on the outlet of the wet scrubber. The heat chamber and scrubber are protected from high temperature levels by an exhaust air temperature monitor. Infrared heat is known to be the most efficient source of heat available for sludge drying applications. As the material reaches the desired dryness, the dry, granular material is emptied into a Department of Transportation-approved container for this sludge.

DoD Need

Improve wastewater sludge reduction, treatment and disposal

Army: CM-7, CM-10

Navy: 2.II.01.q

The dryer is supplied with a single-speed wet scrubber. All exhaust air from the dryer enters the scrubber where the particulate matter is combined for removal with an atomized stream of water. The stainless steel scrubber uses no moving parts and utilizes a high-energy Venturi-type scrubber design. A 1-to-2 gallon-per-minute blowdown stream removes solids to the waste treatment system. The scrubber is over 98% efficient. The blower, mounted on the top of the scrubber package, provides all of the air movement through the dryer.

This sludge dryer was installed at Tobyhanna Army Depot as part of its new Industrial Operations Facility.

Technology Benefits and Advantages

- Volume and weight of solids (a wastewater byproduct) is reduced.

- Labor is reduced from 8 hours minimum per filter press sludge discharge (to handle sludge from pans and decontaminate area) to 2 hours per filter press sludge discharge (to start-up/operate/shut-down dryer and exchange waste drums).
- Refurbished models are typically available at less than half the cost of new equipment. The capital savings in the TYAD procurement, for example, was $36,000.

Technology Limitations

- Air permits may be needed in conjunction with use of a particulate scrubber.
- Technology has operational and maintenance training requirements.

NDCEE FY02 Accomplishments

- Modified installation plans and drawings to reflect dryer utility interfaces and equipment location (FY02).
- Procured and installed a sludge dryer at TYAD that is estimated to reduce 50,000 pounds/year of filter press sulfide sludge to below 20,000 pounds of dry sludge (FY02). To maximize floor space, the NDCEE installed the sludge dryer underneath the sludge filter press. To improve operability, the sludge dryer was placed on casters for servicing.
- Conducted performance testing to ensure that the system meets TYAD requirements (FY02).
- Trained TYAD personnel on the operation and maintenance of the dryer (FY02).
- Conducted a financial analysis of the dryer using projected parameters for the existing filter press TYAD (FY02). The analysis showed that the dryer would assist TYAD in lowering its labor costs, reducing the volume and weight of its solids disposal, and decreasing its operational requirements associated with sludge containment and handling.
- Prepared and submitted a Technical Data Package/Operations & Maintenance Manual (FY02).

Economic Analysis

The economic analysis estimated annual net savings at $16,000, resulting in a payback period of less than 4 years for the implementation of a refurbished sludge dryer (JWI 180G) at TYAD. The equipment cost for the refurbished dryer, including $1,200 for shipping, was $24,200. (New equipment was quoted at $59,850). The savings from mitigating the potential for spillage could not be estimated, and so its value was not included in these analyses. Also, use of hazardous waste sacks instead of 55-gallon drums could improve annual savings to $27,000, resulting in a less than 2.5-year payback.

Suggested Implementation Applications

Sludge dryers were developed for facilities with industrial processes that generate wastewater sludge.

Points of Contact

- Michael Parrent, TYAD, (570) 895-6105, Michael.Parrent@tobyhanna.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@daapgea050.apgea.army.mil
- Paul Brezovec, NDCEE, (814) 269-2844, brezovec@ctcgsc.org

Applicable NDCEE Task

Sludge Drying for Industrial Wastewater Treatment Plant (IWTP) at Tobyhanna Army Depot (Task N.259)

"Smart-Pipe" Infrastructure Analysis

The NDCEE is conducting a project to research, develop, demonstrate and validate intelligent systems for water and wastewater conveyance and storage infrastructures. The project goal is to determine the most practical and cost-effective method for monitoring the health of commonly used materials and sizes of pipes and storage vessels. Consideration would also be given to the compatibility of the new technology with existing water and wastewater systems.

Technology Description

The "smart-pipe" technology is a developing technology area that will provide ongoing, real-time evaluations on the structural health of pipelines or storage tanks using nonintrusive or nondestructive methods. To detect and locate a weakening infrastructure, the ideal system will be fully automated and provide remote monitoring and reporting on pipe wall thickness or strength changes as well as unacceptable loading conditions outside or inside the pipe. The information will provide the basis for optimizing maintenance planning and preventing infrastructure failures and their attendant health, environmental and economic hazards.

The state-of-the-art in leak detection is primarily based on acoustic emission, whereby acoustic sensors detect the energy released from a leaking fluid to locate a leak and to estimate its leakage rate. In addition, the analysis of pressure waves that are generated during a sudden change in fluid flow rate has also been used for leak detection and location. Both of these methods are well established and have been used for leak testing, for the transport and storage of hazardous materials, and to some extent by water utility managers. However, its ability to measure structural weakening prior to actual leakage is currently limited.

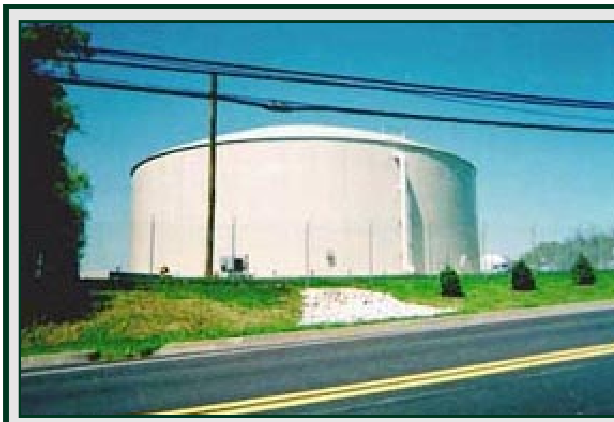
DoD Need

Improved methods for wastewater and drinking water infrastructure monitoring and maintenance

Army: CM-10

Following are four emerging technologies that have been identified by the NDCEE to potentially locate structurally weak areas and predict incipient leaks.

Distributed piezoelectric sensors: These sensors utilize the piezoelectric effect to detect vibrations in rigid structures. Discovered in 1880, the piezoelectric effect is exhibited in some crystalline solid materials that have unit cells without a center of symmetry. These materials, when mechanically stressed, produce an electrical charge. Conversely, when an electric field is applied, the materials produce a mechanical strain that changes the dimensional shape of the material. At present, distributed piezoelectric sensors for smart pipes are made of thick film sensors, piezoelectric composites, piezoelectric polymers or piezometric paint.



The "smart-pipe" technology is being developed to help monitor storage tanks as well as drinking water and wastewater infrastructures.

Instrumented cathodic protection (ICP): A proven electrical technique, ICP is used to prevent metal structures from corrosion through one of two methods. The first method consists of coupling a structural metal (e.g., iron) with a more active metal (e.g., zinc or magnesium), which ends up becoming a sacrificial anode. The second method involves impressing a direct current between an inert anode and the structure to be protected. By using the current, another oxidation process in addition to corrosion occurs at the anodes, and the anodes are not consumed. ICPs are primarily used in metallic structures that are buried in soil or submerged in water, such as is the case with underground utility distribution piping, underground fuel storage tanks, elevated water storage tanks, and navigational structures.

Electrically conducting composite pipes (ECCP): ECCPs use materials that employ the electrical resistance technique, which relies on changes in electrical resistance, or of potential distributions in the laminate, to characterize a damaged structure. This method allows the entire structure to be monitored, whereas the use of embedded or attached sensors tends to restrict monitoring to only selected positions. It is particularly effective for detecting small and subtle material defects in composite structures. A mature version of the technology was patented by Anderson Consulting on January 3, 1995. This version uses a layer of conducting material, in this case, a conducting fabric, as the sensing layer. It can be adapted by one of two ways. It can be inserted as a separate liner or sleeve into old existing pipes or the old pipes can be replaced with new pipes (the recommended method).

Electrochemical-based corrosion sensors: These sensors are based on electrochemical impedance spectroscopy (EIS). They provide very detailed data on the effectiveness of a coating over a relatively small area of less than a square foot. The EIS technique can indicate the presence and rate of corrosion, and the moisture content of the coating prior to corrosion. EIS measurements consist of applying an alternating voltage (5–10 millivolt) to the corroding metal, and measuring the impedance to account for both the magnitude and the relative phase angles of the voltage and current. *In-situ* EIS sensors can monitor or inspect corrosion of boiler tubes, buried pipes, coated steel structures, and, potentially, composite/metal structures.

Technology Benefits and Advantages

- Monitors and improves the predictive maintenance of a wastewater and drinking water infrastructure and storage tanks.
- Although not yet proven, the driver is to reduce environmental costs as well as reduce overall installation and maintenance costs.
- Detects material flaws, wall thinning, loss of structural integrity/joints and loss of protective coating, depending on the technology.

Technology Limitations

- Some methods may be applicable for one specific type of pipe material [e.g., steel pipe or prestressed concrete cylindrical pipe (PCCP)], while others may be applicable to all materials.
- Some technologies are applicable to pipes of all sizes, while others may only be applicable to small diameter pipes.
- None of the technologies can detect temperature loads.

NDCEE FY01 & FY02 Accomplishments

- Conducted a state-of-the art literature review and identified four emerging technologies that can potentially locate structurally weak areas and predict incipient leaks (FY01).
- Determined technical approaches required for integration of smart technology into the conveyance and storage infrastructure. Solicited input from utilities and other relevant sources of relevant expertise (e.g., pipe manufacturers) regarding the findings of the smart-pipe method(s) and technology(ies) (FY02).
- Prepared and submitted a Final Report that documents the results of an investigation on emerging smart-pipe technologies and factors that affect the health of infrastructures (FY02).

Economic Analysis

The United States has about 863,000 miles of pipeline, with about 11,900 miles of new pipes added each year and approximately 4,100 miles of pipeline replaced annually. Since maintaining system integrity can be very painstaking and costly, drinking water distribution companies are constantly looking for technologies that will upgrade and maintain the high quality of service provided to consumers.

Because the smart-pipe technology is in the developmental stages, the NDCEE did not conduct a cost-benefit analysis. However, the technology is expected to yield substantial savings. While the initial capital cost is important, the ongoing costs of operating the pipeline can far outweigh any "savings" made by selecting a pipeline system, which may have a low installation cost but a high risk of failure and a limited working life. Life-cycle costing of alternative pipeline systems will enable service providers to select the most economic solution and provide water at the lowest cost per gallon to the consumer.

Suggested Implementation Applications

The smart-pipe technology should be applicable to any site that must monitor its drinking water or wastewater infrastructure. It should also benefit sites with storage tanks that must be monitored for leakage.

Points of Contact

- Michael Royer, EPA, (732) 321-6633, Royer.michael@epa.gov
- Darlene Bader-Lohn, ODASA(ESOH), ACOR, (410) 436-6861, darlene.bader-lohn@aec.apgea.army.mil
- Paul Brezovec, NDCEE, (814) 269-2844, brezovec@ctcgsc.org

Applicable NDCEE Task

Research, Development, Demonstration and Validation of Intelligent Systems for Conveyance and Storage Infrastructure (Task N.246)

NDCEE Evaluation of Emerging Smart-Pipe Technologies

	Piezoelectric Sensors	EIS Sensors	ICPs	ECCP (Anderson version)	Acoustic emission sensors	ECCP (as a sleeve)
Fully Automated Operation						
Local transducer	Y	Y	Y	Y	Y	Y
Central collection	N	N	Y	N	Y	N
Data analysis	N	N	Y	N	Y	N
Alarm	N	Y	Y	Y	Y	Y
Feedback	N	N	N	N	N	N
Monitoring & Reporting						
Remote	N	N	Y	N	Y	N
Continuous	Y	Y	Y	Y	N	Y
Real time	N	Y	Y	Y	N	Y
Compatible	Y	N	Y	Y	N	Y
Reporting	N	N	Y	N	N	N

NDCEE Evaluation of Emerging Smart-Pipe Technologies (continued)

	Piezoelectric Sensors	EIS Sensors	ICPs	ECCP (Anderson version)	Acoustic emission sensors	ECCP (as a sleeve)
Pipe Failure/Pre-Failure						
Material flaws	N	Y	N	Y	N	Y
Wall thinning	Y	Y	Y	Y	N	Y
Loss of structural integrity/joints	N	N	N	Y	N	N
Loss of protective coating	N	Y	Y	Y	N	Y
Temperature-induced loads	N	N	N	N	N	N
Adaptability/Acceptability to Existing Drinking Water/Wastewater Systems						
Size	Y	Y	Y	Y	Y	Y
Materials	Y	Y	N	Y	N	Y
Life expectancy	N/A	N/A	Y	Y	Y	Y
Joints and connections	Y	N/A	N	Y	N	N
Repair/installation/fabrication	N/A	N/A	Y	Y	N	Y
Implementation						
Capital	N/A	Extremely High	Moderate	High	Low	Low
Operation costs	N/A	High	Moderate	Low	Low	Low
Commercial availability	N/A	N	Y	Y	Y	N
Predictive Capability						
Alert when repair or replacement is required before any system breach or failure occurs	Y	Y	Y	Y	Y	Y
Indicate general location of failure	Y	Y	Y	Y	Y	Y
Provide the remaining service life	N	N	N	Y	Y	Y
Alert when catastrophic failure occurs	Y	Y	Y	Y	Y	Y
Data						
Laboratory-scale	N	Y	Y	Y	Y	Y
Field-scale	N	Y	Y	Y	Y	Y
Installed systems	N	N	Y	Y	Y	Y
Total no. of Ys out of 30	10	14	21	22	15	19
Notes:	Still in development stage	Best if Combined with ECCP	Only works with metal pipes	Best and most cost effective	Only applies to PCCP	

N/A= Not applicable

Smart Wiring

The NDCEE has assisted small- and medium-sized enterprises with commercializing their federally developed or supported technologies, which have both DoD and private-sector applications. For instance, with assistance from the NDCEE, the vendor, Management Sciences, Inc., has obtained endorsements from the Navy P3 and FA/18 Programs for Smart Wiring. Additional Navy programs are currently evaluating the technology for implementation.

Technology Description

Smart Wiring is the embedding of intelligence and sensors in wiring systems to manage the health of wiring and detect abnormalities. It is the preferred method for *in-situ* testing of cables and replaces the use of Time Domain Reflectometry and Frequency-Modulated Carrier Wave Radar.

Wiring systems are ubiquitous in ships, buildings, vehicles, process plants and many other industries. The Smart Wiring system consists of Frequency Domain Reflectometry (FDR) circuitry, a Sentient Instrument Controller (SIC) and a series of embedded microprocessors and sensors. These components, integrated in the Wiring Integration Unit (WIU), can detect abnormalities in wiring systems. The FDR uses a benign low-power sound wave to travel through a wiring harness and return a reflected signal. The SIC monitors the signal and can verify and validate "true" failures, being that the condition of the signal changes as wiring ages and/or develops structural problems.

Technology Benefits and Advantages

- Protects assets from electrical fires and other wiring failures by detecting abnormalities in wiring systems
- Validates suspected wiring system failures
- Improves reliability and thereby increases the availability of assets (such as aircraft) containing wiring devices
- Is the preferred method for *in-situ* testing of cables
- Provides significant capital and operating cost savings in comparison to traditional detection/maintenance methods, as exemplified below

DoD Need

Reduce aircraft downtime due to malfunctioning equipment

Technology Limitations

- Each wire must be individually tested.
- This technology has limited ability to detect frayed or damaged insulation prior to short or open.
- This technology has limited ability to detect corrosion before open circuit.

NDCEE FY01 & FY02 Accomplishments

- Precommercialization funds were used to develop initial requirements for wiring problems on Navy aircraft and to perform an initial cost-benefit analysis (FY01). An onboard unit was begun in FY01 and completed in FY02. (There was no direct NDCEE involvement in the manufacturing process, but its investment in the bench prototype during FY99 resulted in the ability to build the onboard unit.)
- Smart Wiring was highlighted in *Aviation Week* and *Space Technology* in March 2001 (FY01).
- Technology candidate was transitioned to FY02 effort where it is anticipated that in-flight tests will occur during FY02–FY03.

Economic Analysis

The Future Naval Capabilities - Total Ownership Costs has estimated that the Smart Wiring system will yield an estimated cost savings of $64.8 million per year after full implementation. The technology will reduce the time required to troubleshoot aircraft wiring systems by 20% (saving of 200,000–400,000 labor hours per year); reduce mission aborts and nonmission capable hours due to wiring incidents by 20% (saving $34.5 million per year); reduce in-flight electrical fires and subsequent loss of aircraft (saving $27.3 million per year); and reduce false equipment removal by 20%.

Suggested Implementation Applications

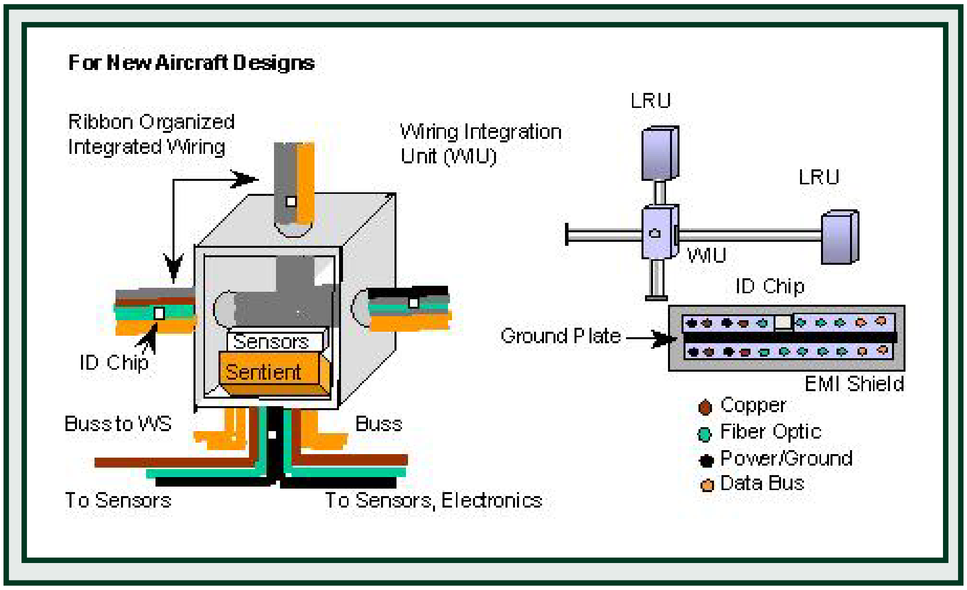
Smart Wiring can be integrated into any system where a failure in the wiring harness is catastrophic. For example, it can be integrated into aircraft wiring systems, including flight demonstration systems. Presently, the Navy P3 and FA/18 Programs have endorsed Smart Wiring. The Navy C-2, E-3 and B-22 programs are currently evaluating the technology for implementation.

Points of Contact

- Hany Zaghloul, CERL, (217) 373-3433, Hany.Zaghloul@hqda.army.mil
- Gary Grimm, ODASA(ESOH), (410) 436-6860, gary.grimm@daapgea050.apgea.army.mil
- William Tumblin, II, NDCEE, (864) 271-8218, tumblin@ctcgsc.org

Applicable NDCEE Task

Commercialization of Technologies to Lower Defense Costs (Task N.224)



The Smart Wiring system consists of FDR circuitry, a SIC and a series of embedded microprocessors and sensors. These components, integrated into the WIU, can detect abnormalities in wiring systems. The FDR uses a benign low-power sound wave to travel through a wiring harness and return a reflected signal. The SIC monitors the signal and can verify and validate "true" failures being that the condition of the signal changes as wiring ages and/or develops structural problems.

Sodium Bicarbonate Blasting

Under previous efforts, the NDCEE and Naval Surface Warfare Center Carderock Division tested alternatives, including Sodium Bicarbonate Blasting, to current coatings removal and etching methods at the NDCEE Demonstration Facility. The NDCEE utilized these efforts to help identify potential alternatives to chemical or mechanical coatings removal processes for use on delicate substrates, many of which are also dimensionally critical parts.

Technology Description

Sodium Bicarbonate Stripping processes can be used as alternatives to traditional chemical paint strippers, hand sanders and manual cutting tools. Sodium bicarbonate (also known as bicarbonate of soda) is a soft blast medium with a higher specific gravity and less hardness than most abrasives. The effectiveness of sodium bicarbonate depends on optimizing a number of operating parameters, including nozzle pressure, standoff distance, angle of impingement, flow rate and traverse speed. This process can clean and depaint such items as stainless steel, aluminum, galvanized metal, concrete, ceramic tile, glass, plastics, fiberglass, rubber and neoprene.

This process can be used with or without water. It is most frequently used with water, which acts as a dust suppressant. In this form, compressed air delivers sodium bicarbonate media from a pressure pot to a nozzle, where the media mixes with a stream of water. The soda/water mixture impacts the coated surface and removes old coatings from the substrate. The water dissipates the heat that is generated by the abrasive process, reduces the amount of dust in the air and assists in the paint removal by hydraulic methods. Workers do not need to prewash or mask the surface of the material being stripped. Settling or filtration can separate the solid residue that is present in the wastewater.

The use of sodium bicarbonate in its dry form (or when not fully mixed with water) can create a cloud of dust that will require monitoring and may require containment to meet air standards. Though the dust that is generated is not an explosive hazard, the airborne particulates that are generated from the stripping operation can contain toxic elements that are found in the paint being removed. This stripping process should be performed in areas where exhaust particulates can be contained and/or exhaust ventilation system controls are present to remove hazardous airborne metals.

DoD Need

Environmentally preferred coatings removal technique

Army: CM-3, CM-9, P2-1

Navy: 2.I.01.g, 3.I.05.a

Air Force: 580, 1232, 120, 225, 311, 814, 988, 1468

Technology Benefits and Advantages

- Eliminates the use of chemical strippers
- Reduces labor and operating costs as a result of decreased preremoval preparation and postremoval cleanup

Technology Limitations

- Wastewater and waste solids must be analyzed to determine disposal requirements.
- Media cannot be recycled.
- The use of sodium bicarbonate in its dry form (or when not fully mixed with water) can create air emissions that will require monitoring and may require containment to meet air standards.
- If the operating temperature of the part is at or above the temperature 140–160ºF, the residual sodium bicarbonate may become corrosive.
- NAVAIR and the Air Force currently limit the use of sodium bicarbonate stripping to specific approved applications that have no possibility of trapped residual sodium bicarbonate.

NDCEE FY02 Accomplishments

- Produced an Alternatives Report that identified the needs and requirements for alternative coatings removal technologies from delicate substrates (FY02). Sodium bicarbonate blasting was recommended for evaluation of PCMS tiles and radomes.
- Produced a Demonstration Report that summarized the results of all activities (FY02). The NDCEE recommended that further evaluations and testing of this alternative be conducted with advancements made to the containment devices.

Economic Analysis

Equipment costs range from $15,000 to more than $40,000. Although the NDCEE has not conducted a cost-benefit analysis, operating costs are expected to be substantially less than chemical stripping.

Suggested Implementation Applications

Potential applications include weapons system components such as PCMS tiles on submarines and radomes from ships and aircraft.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org
- Georgette Kotsagrelos, NDCEE, (412) 577-2655, kotsagre@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Spent Acid Screening Process

The NDCEE improved the Spent Acid Screening Process at Radford Army Ammunition Plant by modifying the screens and installing them in a more optimal location for better functionality. This process improvement was based on findings from an NDCEE engineering review of the nitration process at RFAAP. The objective was to reduce the environmental impact and costs associated with the discharge of acidic waste from the RFAAP nitrocellulose manufacturing process.

Technology Description

The Spent Acid Screening Process removes NC fines prior to storage of the acid for future use and is one of the final steps in an NC-based propellant manufacturing process. During nitration, cellulose and mixed acid are continuously fed to a series of stirred reaction vessels. The slurry of NC fibers and spent acid exits the final reactor vessel and is fed to a centrifuge, where the NC fibers are separated from the spent acid. The centrifuge uses a series of counter-current wash streams to reclaim entrained acid by displacement with water. The NC fibers are then mixed with water and pumped to the stabilization process. The spent acid that is collected from the centrifuge contains NC fines, so the acid must undergo further treatment to remove the fines prior to storage of the acid for future use.

The original RFAAP method for removing fines from the spent acid was to pump the acid over a sloped screen. The acid flowed through the screen, leaving the trapped fines to tumble down the screen into a collection trough at the bottom. A water stream was used to reintroduce the fines to the NC product stream after the centrifuge. While the sloped screens removed most of the spent acid from the NC fines, some of the acid remained entrained in the fines and ultimately returned to the product stream of NC fibers. The NC was repeatedly rinsed and boiled for stabilization, so any acid carried with the NC also would be discharged with the wastewater.

To reduce acid discharge levels, the NDCEE redesigned the Spent Acid Screening Process by modifying the screen enclosures and installing them in a location where the fines could tumble off of the screen into the product stream as it leaves the final reactor vessel. As a result, the acid that is entrained in the NC fines after screening is removed by the centrifuge and eliminated from the NC product stream. This process improvement increased production efficiency in two ways. First, by recovering a greater percentage of the NC fines and placing them back into the production process, the amount of usable product manufactured is increased. Subsequently, disposal costs are reduced because the amount of waste NC created has been decreased. Second, the amount of acidic waste is reduced because more product is passed through the centrifuge, allowing more acid to be recovered for future use. The result is a savings on both purchase and disposal costs.

DoD Need

Improved munitions manufacturing processes

Army: CM-10, CM-5, P2-5

Spent acid screening operation at RFAAP

Technology Benefits and Advantages

- Improves safety and worker health conditions
- Increases the volume of usable NC fines through acid removal
- Decreases the amount of NC and acid waste generated
- Reduces waste disposal costs
- Reduces raw material quantities and costs through acid recovery

Technology Limitations

- While the useful life of the acids used in the NC process has been significantly extended, the acids must still be replenished after a given amount of time.

- Waste acids are still generated and must be treated or disposed of according to applicable regulations.

NDCEE FY01 & FY02 Accomplishments

The NDCEE conducted a baseline analysis of RFAAP's current Spent Acid Screening Process and identified seven feasible alternative separation techniques to replace the current bar screen filter that is used to separate acid and nitrocellulose fines. After reviewing these techniques, the NDCEE redesigned and installed a new Spent Acid Screening Process.

Economic Analysis

The total estimated cost for a turnkey installation at RFAAP was $185,000. Based on an estimated annual cost savings of approximately $850,000, the new process had a payback period of three months.

Suggested Implementation Applications

DoD facilities that are engaged in propellant manufacturing operations are candidates for implementation.

Points of Contact

- Robert Davie, RFAAP, (540) 639-7612, Robert_Davie@atk.com
- Nelson Colon, IEC, (973) 724-2482, ncolon@pica.army.mil
- David James, NDCEE, (814) 269-6455, james@ctcgsc.org

Applicable NDCEE Task

Radford Environmental Development and Management Program (REDMAP) (Task N.225)

Sponge Blasting

Under previous efforts, the NDCEE and Naval Surface Warfare Center, Carderock Division tested alternatives at the NDCEE Demonstration Facility, including Sponge Blasting, to current coatings removal and etching methods. The NDCEE utilized these efforts to help identify potential alternatives to chemical or mechanical coatings removal processes for use on delicate substrates, many of which are also dimensionally critical parts.

Technology Description

Sponge Blasting is a technology that uses sponge media to clean, etch and remove coatings from various types of substrates. The Sponge Blasting system uses an air-propelled open cell, water-based polyurethane foam cleaning media. The foam material can be impregnated with abrasive grit to enhance the performance of the media. The abrasive media may contain a variety of grit including aluminum oxide, steel and plastic. The ability to use different media types gives the system flexibility by providing different characteristics and blasting capabilities. The foam cleaning media are absorptive, and when wetted with a cleaner or surfactant, can be used to remove a variety of surface contaminants and control dust without excess wastewater.

A feed unit is used to deliver sponge media to the surface. A media classifier is required to handle recycling chores. This classifier operates by collecting the sponge blast media and running the media through an electrically powered sifter, which separates the sponge media into four categories: oversized debris, reusable debris, reusable media, and fines (consisting of spent media and dust). Typically, 85–90% of the sponge media is reusable after each blast cycle. Using a classifier, the media can be recycled approximately 5–7 times for low dust applications. The amount of times the media can be recycled depends on the type of surface and the contaminants removed from the surface. Some applications have shown up to 18 uses before the media are no longer productive.

Typically, the waste that is generated with sponge media blasting is minimal because the media are recyclable. The disposal method depends on the type of coating or substance that was removed from the surface. Generally, if the substance that is being removed is classified as nonhazardous waste, then the spent media and the material that was removed may be put in a drum and sent to a landfill. If the substance that is being removed is classified as a hazardous waste, such as a radioactive material or a lead-based paint, then it must be placed in an approved container (55-gallon drum) and sent to an approved disposal facility.

DoD Need

Environmentally preferred coatings removal technique

Army: CM-3, CM-9, P2-1

Navy: 2.I.01.g, 3.I.05.a

Air Force: 580, 1232, 120, 225, 311, 814, 988, 1468

Technology Benefits and Advantages

- Decreases solid waste and eliminates the use of chemical strippers
- Reduces labor and operating costs as a result of decreased preremoval preparation and postremoval cleanup
- Improves safety and worker health conditions due to the elimination of airborne emissions of heavy metals and other contaminants when used with vacuum recovery
- Involves reusable media
- Helps facilities comply with Executive Order 13148, which requires DoD to decrease the amount of waste generated at federal facilities, as well as environmental regulations regarding airborne particulate emissions

Technology Limitations

- Not as aggressive on metallic substrates as some abrasive media. However, unlike the sponge medium, these more abrasive media do not have the capability to be used on delicate substrates.

NDCEE FY02 Accomplishments

- Produced an Alternatives Report that identified the needs and requirements for alternative coatings removal technologies from delicate substrates (FY02). Sponge Blasting was recommended for evaluation on HMMWV hoods.

Economic Analysis

Equipment costs are approximately $50,000. Although the NDCEE has not conducted a cost-benefit analysis, operating costs are expected to be substantially less than chemical stripping.

Suggested Implementation Applications

Applicable weapons system components include fiberglass hoods on HMMWVs and other delicate substrates.

Points of Contact

- Gary Grimm, ODASA(ESOH), (410) 436-6860, Gerhard.Grimm@aec.apgea.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org
- Georgette Kotsagrelos, NDCEE, (412) 577-2655, kotsagre@ctcgsc.org

Applicable NDCEE Task

Pollution Prevention Initiative (Task N.227, Mod 1)

Supercritical Carbon Dioxide System

Based on its extensive technical expertise with coating technologies, the NDCEE was tasked to evaluate the Linden Industries UNICARB $SCCO_2$ System as an alternative to the compressed-air HLVP application system currently used in aircraft coating applications. As part of its evaluation, the NDCEE conducted a demonstration of the system at its NDCEE Demonstration Facility.

Technology Description

The $SCCO_2$ System is a coating application system designed to increase coating transfer efficiency and reduce application VOCs by replacing coating solvents with $SCCO_2$. The system incorporates three pieces of equipment: a portable control panel, a portable intrinsically safe coating and a CO_2 pumping and conditioning station. The system also uses a Nordson HVLP applicator (hose and gun) with special fluid nozzles. The control panel supplies a 220-volt power supply for system heaters, supply pumps and a mixed coating re-circulation system. The control panel also supplies low-pressure air for pneumatic logic circuits to control mixing valves. The coating pumping and mixing platform contains storage racks for CO_2, nitrogen and the coating. The platform contains high-pressure pumps for the liquid CO_2 and the coating, the mixed coating accumulation and heating system, and a recirculation pumping system. The system also contains filters, dump valves and piping, and temperature/pressure gauging to monitor and regulate system conditions.

The high solids formulated coatings (75%+) are mixed with supercritical (1600 pounds per square inch @ 45°F) liquid CO_2 (solvent replacement) and pumped under high pressure to the applicator. Applicator spray nozzles are designed to permit liquid CO_2 to undergo a phase change and expand as a gas through a controlled mechanical expansion tube. A fluid nozzle pre-orifice device is used to limit pressure losses beyond the nozzle to keep the CO_2 in liquid phase along with the coating. Gaseous CO_2 then explodes from inside the nozzle tip as the coating stream experiences rapid decompression (from 100 atmosphere, standard to 1 atmosphere, standard) at the applicator. The “explosion” overcomes the molecular attraction forces of the coating and provides a high degree of atomization.

Technology Benefits and Advantages

- Improved transfer efficiencies
- Less VOCs than current compressed air HLVP application systems

Technology Limitations

- Need tight control of liquid CO_2 quantity, pressure and temperature to produce an acceptable coating application
- Potential to exhibit “foaming,” which occurs when the liquid CO_2’s solubility with the coating resin and solvent systems produce significantly different release rates

NDCEE FY01 & FY02 Accomplishments

- Produced a Recommendations Report (FY01) that identified two coating application equipment systems that potentially could achieve improved atomization and improved transfer efficiency compared to a baseline compressed air HVLP application system. The selected coating application equipment systems were the Can-Am COTAIR Turbine-Heated Air HVLP system and the Linden/Nordson $SCCO_2$ application system.

DoD Need

Environmentally preferred coating application system

Army: CM-3, P2-1

Air Force: 805

Navy: 2.I.01.g, 3.I.04.h

- Conducted demonstrations of a Can-Am COTAIR Turbine-Heated Air HVLP system and the Linden/Nordson $SCCO_2$ application system at the NDCEE Demonstration Facility (FY01).
- Produced a Coatings Application Equipment Evaluation Final Report (FY02) that documented the results of the demonstrations and provided financial analyses based on the ECAM^{SM} tool. Demonstration results showed that although the $SCCO_2$ application system can apply high-solids coatings at a higher transfer efficiency than the baseline HVLP system, the $SCCO_2$ system could not consistently apply the selected task aerospace coatings. Therefore, the $SCCO_2$ system was not recommended for further validation and qualification work.

Economic Analysis

An ECAM^{SM} of the $SCCO_2$ system was not performed because of the system's instability and its inability to apply task-selected aerospace coatings.

Suggested Implementation Applications

None

Points of Contact

- Mike Wrazen, Industrial Ecology Center, (973) 724-3730, mwrazen@pica.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Scott Sager, NDCEE, (814) 269-6457, sager@ctcgsc.org

Applicable NDCEE Task

Coatings Application Equipment Evaluation (Task N.000-01, Subtask 3)

Thermophilic (Biological) Process

The NDCEE has demonstrated and evaluated the feasibility of a pilot-scale Thermophilic (Biological) Process (TBP) plant at Milan Army Ammunition Plant. Through this demonstration project, the NDCEE determined that the process is technically sound, economically viable and environmentally safe. Under optimized conditions, the process consistently degraded over 90% of the nitrobodies from loaded granular activated carbon (GAC). Based on the successful findings, the NDCEE transitioned the plant to the Iowa Army Ammunition Plant and trained two IAAAP operators on the use of the pilot plant. The NDCEE, after completing three successful tests, decontaminated and decommissioned the pilot plant and returned it to the NDCEE Demonstration Facility.

Technology Description

TBP was developed to treat pink water, which is explosive-laden wastewater originating from two munition functions: 1) load, assemble and pack; and 2) demilitarization. The technology also has demonstrated control of discharges from DoD-wide ammunition processing operations such as the water-dry propellant extraction waste in the sumps of ammunition plants. Although additional research is required, the TBP process potentially could be adapted to treat explosives-contaminated groundwater and soils.

TBP is a modification of the U.S. Army's present method of GAC regeneration systems. Currently, AAPs meet pink water discharge requirements by removing the contaminants using GAC adsorption systems. The explosive-laden GAC is either regenerated for reuse or incinerated for disposal. Under the present method, regeneration often does not achieve Army requirements, and the GAC must be disposed of as a hazardous waste. TBP utilizes the GAC to adsorb the explosives from the wastewater, followed by base hydrolysis and thermophilic (biological) regeneration of the GAC. The treated wastewater is sent to a wastewater treatment plant.

DoD Need

Treatment of explosive-laden wastewater (pink water)

Army: CM-5, CM-10, P2-5

Navy: 2.III.01.v, 2.II.01

The process begins with the pink water flowing into the GAC adsorption system. The explosive contaminants are first adsorbed onto the GAC, which has demonstrated a high affinity and capacity for these nitrobody compounds. After an adsorption cycle, flow through the GAC column stops and recirculation of a regeneration solution starts. The GAC column is first heated to 176°F (80°C) for base (caustic) hydrolysis, and then cooled to 131°F (55°C) for thermophilic regeneration, inoculated with explosives-degrading organisms and aerated. The column becomes a bioreactor. Thus, explosive compounds, concentrated by the previous adsorption step, are depleted, and the GAC in the column is regenerated. The bioreactor fluid, containing natural organisms and enzyme systems, passes to the industrial wastewater treatment plant. In the last step, the regenerated GAC column cools and is placed on stand-by.

Prototype TBP unit

Technology Benefits and Advantages

- Biodegrades most nitrobodies in explosives-laden wastewater and renders them nontoxic, according to results from toxicity testing using the Microtox® instrument
- Regenerates loaded GAC columns, *in situ*, avoiding the risks and losses associated with handling and incinerating and/or regenerating the spent GAC by combustion
- Can be retrofitted to the existing GAC adsorption systems, with only minor modifications
- Requires less energy than other processes currently in use
- Is commercially available, economically viable and environmentally safe

- Poses no safety or health risks; however, several contaminants in the explosive-laden wastewater are dangerous and precautions should be taken

Technology Limitations
- Operator training is required.
- Capital costs may be substantial.

NDCEE FY01 & FY02 Accomplishments
- Transitioned a TBP pilot-scale plant to the IAAAP for demonstration purposes (FY01). The NDCEE had previously installed and operated this plant at the MLAAP. The plant is capable of processing 1.5–2.0 gallons per minute. The TBP skid equipment is self-contained and consists of three GAC columns, a regeneration tank, pumps, air compressor, a chemical injection system, and instrumentation/controls.
- Conducted three tests of the loading and regenerating cycle using spent GAC provided by the IAAAP. The results showed a destruction and removal efficiency (DRE) of explosives from the GAC surface of 99.2%, 98.4%, and 99.2%, respectively. The DRE is the difference in the amount of nitrobodies on the GAC, before and after regeneration, and is reported as a percentage of the total loading of nitrobodies on the GAC. The U.S. Army required a minimum DRE rate of 90% (FY01).
- Produced a Final Report that documented and summarized the TBP demonstration activities conducted at the MLAAP and the IAAAP (FY01).
- Identified Proponent and Justification Requirements for Rock Island Arsenal (FY02). A Justification Report has been prepared to determine the technical and economical feasibility of implementing the technology at the IAAAP.
- Initiated effort to demonstrate the TBP technology for the treatment of nitrate esters in wastewater generated by Naval Surface Warfare Center, Indian Head (FY02).

Economic Analysis
No other cost-effective alternatives to GAC adsorption systems were found that could treat the explosive-laden pink water. The capital cost to retrofit the TBP technology to an existing 20-gallons-per-minute system is approximately $230,000; however, this cost may be insignificant compared to that of conventional GAC adsorption systems. The TBP technology can be used for pink water remediation at an estimated cost of $10–$15 per 1,000 gallons treated. Competitive technologies were found to cost more than twice that amount.

Suggested Implementation Applications
The TBP technology was designed to treat pink water and potentially may be able to treat explosives-contaminated groundwater and soils. Pink water by definition is a RCRA K047 Hazardous Waste due to the presence of nitrobodies, including 2,4,6 trinitrotoluene (TNT), cyclotrimethylene-trinitramine (RDX), and cyclotetramethylene-tetranitramine (HMX). The exact composition of pink water is highly variable and is dependent on process materials and operations. The maximum concentration of dissolved energetic-related pollutants, in pink water, is 200 parts per million. Statutes also mandate that pink water be treated prior to disposal.

Points of Contact
- Joe Argento, Industrial Ecology Center, (973) 724-2428, argento@pica.army.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Dr. Mahmood Qazi, NDCEE, (814) 269-2729, qazi@ctcgsc.org

Applicable NDCEE Tasks
Sustainable Green Manufacturing (Tasks N.213 and N.301, Subtask R2-8)

Ultrahigh-Pressure Waterjet Technology for Adhesive Bonding Applications

Based on its extensive technical expertise with coating removal technologies, the NDCEE was tasked to evaluate the waterjet process as an alternative surface activation process for the preparation/activation of aluminum and titanium surfaces prior to sol-gel application for adhesive bonding. As part of its evaluation, the NDCEE conducted demonstration testing at its Technology Demonstration Facility.

Technology Description

The ultrahigh-pressure waterjet (UHPWJ) is a cleaning/coatings removal technology that utilizes a highly pressurized water stream from 3,000–55,000 pounds per square inch to quickly and safely perform precision industrial applications such as cutting, cleaning, degreasing, debonding, decoating and depainting. UHPWJ is commonly used by the DoD and industry as an alternative to abrasive blasting and also has been successfully demonstrated to offer corrosion-free surface preparation when used with a closed-loop system. It may also be able to provide a method for activating the surface of aluminum and titanium substrates for adhesive bonding applications.

The NDCEE conducted an investigation to evaluate a waterjet process as an alternative surface activation process for the preparation/activation of aluminum (2024-T3 and 7075-T6) and titanium (Ti-6Al-4V) surfaces prior to sol-gel application for adhesive bonding. Promising sol-gel chemistries have been developed over the past several years and are part of the ongoing Strategic Environmental Research and Development Program (SERDP) project PP-1113. However, development of the surface activation step prior to sol-gel application is a key challenge that must still be resolved. The surface activation step must create the proper metal surface morphology and chemistry so that the sol-gel solution can chemically bond to the surface and provide the required long-term bond durability. Currently, strong acid or base solutions (sometimes including chromium) are required to properly prepare surfaces prior to bonding. The waterjet process was investigated to determine if it could combine numerous processing steps into one convenient operation that would provide a fully activated surface and eliminate the use of hazardous chemicals.

DoD Need

Environmentally preferred surface preparation technique

Army: P2-6

Navy: 2.I.01.g, 3.I.03.e

Also as part of this investigation, the waterjet was used to prepare (clean, deoxidize and roughen) aluminum (2024-T3 and 7075-T6) surfaces as part of a proprietary nonchromate surface preparation process using an organosilane formulation developed by Cape Cod Research, Inc. Like the sol-gel, the organosilane material is another more environmentally friendly potential alternative to the currently used processes.

UHPWJ used for surface activation of aluminum adherends.

Technology Benefits and Advantages

- Capable of both removing contamination and activating the surface in a single step, thereby eliminating the need for a solvent degreasing step prior to surface activation
- Improved safety and worker health conditions due to the elimination of hazardous chemicals such as hexavalent chromium and volatile organic compounds
- Automated, robotic system that is fairly simple to operate and maintain

Technology Limitations

- While the UHPWJ technology is mature and widely used as a paint stripper, its use as an alternative surface activation process for the preparation/activation of aluminum and titanium surfaces is still under investigation to fully optimize the process.
- Substantial capital equipment investment is required. UHPWJ systems can cost over $1 million.
- Training is required in operation and maintenance.

NDCEE FY01 & FY02 Accomplishments

- Conducted two demonstration trials for both the sol-gel and organosilane materials at the NDCEE Demonstration Facility (FY01). The first trial consisted of conducting an initial round of waterjet processing/parameter development by the NDCEE, followed by wedge crack extension testing at the Air Force Research Laboratory (AFRL). Results of the initial processing were used to evaluate parameters for waterjet blasting so that optimal parameters could be determined prior to the second trial of processing. The second trial was used to verify the initial results as well as test additional parameters based on the first trial data.
- Produced a Final Report that documented the demonstration findings, which showed that the UHPWJ process is a potential alternative for surface activation of aluminum 2024-T3 prior to sol-gel application (FY01). However, additional testing may be justified to determine if waterjet activation is a viable alternative for surface activation of titanium Ti-6Al-4V and aluminum 7075-T6 prior to sol-gel application. In addition, because test conditions were less than ideal due to shipping samples to AFRL, further testing may be justified to determine the full potential of waterjet activation followed by organosilane application as a prebond surface preparation technique. With the original samples, the organosilane material failed to meet ARFL requirements.

Economic Analysis

Reduction of VOCs and hexavalent chromium compared to current processes, coupled with elimination of strong acids and rinsing steps, will result in considerable cost savings due to the avoidance of the need for hard controls and reduced waste tracking, handling and disposal. For instance, at Warner Robins Air Logistics Center, Georgia, sol-gel surface preparation is expected to eliminate up to 30 pounds of hexavalent chromium and 2,500 pounds of VOCs per year. With waterjet to also replace the initial solvent wiping step, an additional 20,000 pounds per year of VOC can be eliminated.

Suggested Implementation Applications

Once the waterjet activation technique meets ARFL requirements, the following weapons systems would be candidates for implementation: EA-6B, F-14, C-14, C-130, C-5, F-18, F-16, SH-60, AH-64, Marine amphibious vehicles, portable tactical shelters, and commercial aircraft.

Points of Contact

- Jim Mazza, AFRL, (937) 255-7778, james.mazza@wpafb.af.mil
- Albert Walker, ODASA(ESOH), (410) 436-6867, Albert.Walker@daapgea050.apgea.army.mil
- Heidi Nicely, NDCEE, (814) 269-6461, nicely@ctcgsc.org

Applicable NDCEE Task

Waterjet and Organosilane Evaluation for Adhesive Bonding Applications (Task N.249)

Ultrahigh-Pressure Waterjet Technology for Coatings Removal Applications

The NDCEE has extensive technical expertise with coatings removal using water-blasting technologies. A water-blasting system that can be operated either manually or with a robot has been a featured component of the NDCEE Demonstration Facility for nearly a decade. Several DoD facilities, as well as commercial industry, have used the Demonstration Facility to explore the technology's viability for their site-specific needs. Once the technology has been validated to be technically and economically beneficial for a facility, the NDCEE provides implementation and training assistance to the facility. Most recent beneficiaries of the NDCEE's coatings removal knowledge include Schofield Barracks, Fort Eustis, and Combat Equipment Group-Afloat. Past beneficiaries include Crane Army Ammunition Activity; Naval Air Depot - Jacksonville; Naval Surface Warfare Center, Carderock Division; Norfolk Naval Shipyard; and Corpus Christi Army Depot.

Technology Description

Water blasting uses the impact force of highly pressurized water to effectively strip a wide variety of organic coatings from part surfaces. The main difference among water blasting systems is the pressure of the water used. Low-pressure and high-pressure water systems generally use a hand-held lance to apply the blast water to the surface being cleaned or stripped, allowing for a broad variety of water-blasting applications. At a pressure of approximately 25,000 pounds per square inch, the force of water leaving the blast nozzle is too great for a person to control by hand. These UHPWJ systems use a robotic arm to hold the blast nozzle at the proper distance and angle from the part surface. The high degree of control and repeatability from the robot enables automated UHPWJ systems to remove light coatings from delicate surfaces.

DoD Need

Environmentally preferred cleaning and coatings removal technique

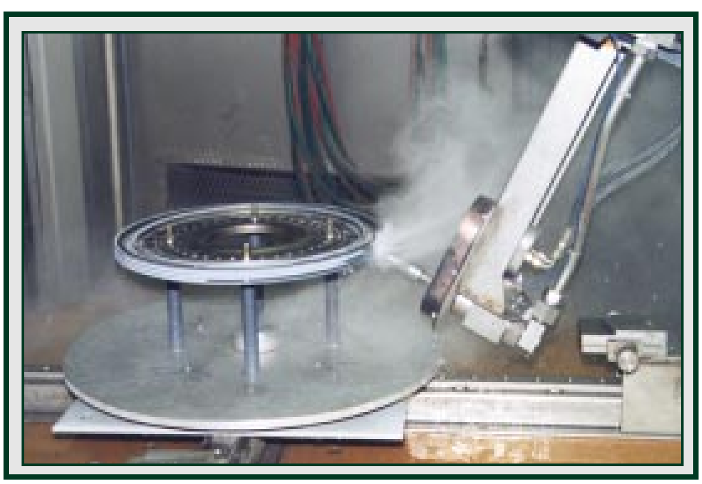
Army: CM-3, CM-9, P2-1

Navy: 2.I.01.g, 3.I.05.a

Air Force: 1232, 120, 225, 311, 814, 988, 1468

The UHPWJ is used to quickly and safely perform precision industrial applications such as cutting, cleaning, degreasing, debonding, decoating and depainting. It is commonly used by the DoD and industry as an alternative to abrasive blasting, and also has been successfully demonstrated to offer corrosion-free surface preparation when used with a closed-loop system.

Water-blasting technologies produce little waste. Additionally, with the correct training and upkeep, the process is fairly simple to operate and maintain. A primary advantage to this process is that it minimizes, and in some cases eliminates, part preparation steps such as masking. Therefore, time is reduced and additional materials and solid waste are eliminated.



Removal of Flame Spray Coating Using UHPWJ

In an investigation conducted on behalf of TACOM, the NDCEE determined that a manual UHPWJ system is effective at removing paint and preparing surfaces of Army tracked and wheeled vehicles. As part of its investigation, the NDCEE designed and constructed a user-friendly, portable closed-looped UHPWJ system that uses water pressures up to 36,000 pounds per square inch. The system consists of a heavy nylon-shelled shelter that is 28-feet long x 24-feet wide x 17-feet high. It is supported by a metal pole construction skeleton and lighted with nine waterproof double fluorescent lights suspended from the ceiling. To maximize visibility, the shelter uses two 6000-cubic feet per minute ventilation units that are mounted on opposite sides. The shelter rests within an inflatable subfloor that consists of a heavy vinyl floor and individually inflatable berms to contain process water. The system meets all National Emission Standards for Hazardous Air Pollutants and Control Techniques Guidelines. The shelter, with minor modifications, has been transitioned to Schofield Barracks, where it has been in use since 2001.

Technology Benefits and Advantages

- Eliminates hazardous airborne particulate from blasting operations, decreases solid waste by 90%, and eliminates the use of chemical strippers
- Minimizes, and in some cases eliminates, part preparation steps such as masking
- Reduces labor and operating costs as a result of decreased pre-removal preparation and postremoval cleanup
- Improves safety and worker health conditions due to the elimination of airborne emissions of heavy metals and other contaminants when used with vacuum recovery
- Automated systems, both stationary and portable, are available and fairly simple to operate and maintain
- Helps facilities comply with Executive Order 13148, which requires DoD to decrease the amount of waste generated at federal facilities, as well as environmental regulations regarding airborne particulate emissions
- Allows facilities to maintain a higher degree of readiness by eliminating the dependence on outside media suppliers

Technology Limitations

- Capital equipment investment may be significant. Manual systems are available for $100,000–$120,000, while some robotic systems may cost over $1 million.
- Technology has operational and maintenance training requirements.

NDCEE FY01 & FY02 Accomplishments

- Participated as a presenter in the Eleventh Annual International Workshop on Solvent Substitution and the Elimination of Toxic Substances and Emissions (FY01). The presentation described: the DoD's regulatory need to find an alternative to abrasive blasting, the NDCEE-designed and -constructed UHPWJ system, and the successful demonstration results. Initial demonstrations occurred in 1999 at the NDCEE Demonstration Facility on a Bradley Fighting Vehicle, M1 Abrams Tank, HMMWV and 2.5-ton dump truck. Based on successful test results, field demonstrations were held in 2000 at Aberdeen Test Center, Fort Hood, and Schofield Barracks.
- Delivered a Recommendations Report to Fort Eustis (FY01), which is planning to implement NDCEE's recommendation for a paint blast facility in FY02. The NDCEE recommended that Ft. Eustis personnel view a demonstration of UHPWJ blasting capabilities on vehicle frames and components.
- Delivered a Recommendations Report to Combat Equipment Group-Afloat to improve current coatings removal operations and provide a conceptual design for equipment enclosures for implementation (FY02).
- Produced an Alternatives Report that identified the needs and requirements for alternative coatings removal technologies from delicate substrates (FY02). Delicate substrates are materials that may be easily damaged by chemical or mechanical coatings removal processes. UHPWJ was recommended as an alternative to remove coatings from special hull treatment (SHT) tiles.
- Produced a Demonstration Report that summarized key results used to assess alternative coatings removal technologies and compared their performance to the baseline removal methods (FY02). This alternative UHPWJ process was

demonstrated at Norfolk Naval Shipyard in May 2001. At a pressure of approximately 30,000 pounds per square inch, the automated UHPWJ technology removed polyurethane coatings from SHT at an average rate of 270 square feet per hour, a noticeable improvement over the current removal rate of 12 square feet per hour. To remove nonskid coatings from a submarine steel hull, the average removal rate for open- and closed-cycle UHPWJ tools was 175 square feet per hour, which is more than a 50-fold increase from the baseline process of abrasive blasting. UHPWJ was recommended for implementation in these applications.
- A cost analysis was completed using the ECAM^{SM} tool to ensure that environmental, safety and health issues associated with these processes were included. The results of the ECAM^{SM} were summarized in the Justification Report (FY02).

Economic Analysis

As part of its UHPWJ blasting investigation on Army tracked and wheeled vehicles, the NDCEE conducted a financial analysis that compared the UHPWJ system to conventional abrasive blasting for two types of maintenance activities (HMMWV and dump truck) at both depot and field levels. The analysis was based on the ECAM^{SM} tool.

Based on a 15-year study period, the ECAM^{SM} results revealed that it would be in the best financial interest for field-level maintenance facilities to change their current processes and each implement a UHPWJ system. The approximate annual operating cost benefit is $83,000–$110,000. The corresponding discounted payback periods are approximately 3.5 years and 5 years, respectively. The 15-year NPV is projected to be $2.3 million; the IRR is 23%.

Under another effort, a cost-benefit analysis was conducted on the use of the UHPWJ for three coatings removal applications: polyurethane from SHT, nonskid from steel and SHT residual from steel. All three applications were combined into one cost analysis. Additionally, all options on the UHPWJ equipment were included in the initial capital costs, making the total system cost approximately $1.2 million. Several options exist for a facility to select a less expensive system depending on the application and workload. The UHPWJ showed good potential labor, materials, and maintenance cost savings, but a low NPV and IRR. The simple and discounted payback periods are 4.2 and 4.6 years, respectively.

Suggested Implementation Applications

Because of its high versatility, UHPWJ blasting has applications in several industries, including automotive, aerospace, shipbuilding and construction. As a cleaning process, water blasting is efficient at removing oil and grease from parts with simple geometries and removing particulates from parts with complex geometries to precise cleanliness levels. Applicable weapons system components include ship and aircraft radomes, SHT tiles on submarines, and fiberglass hoods on HMMWVs.

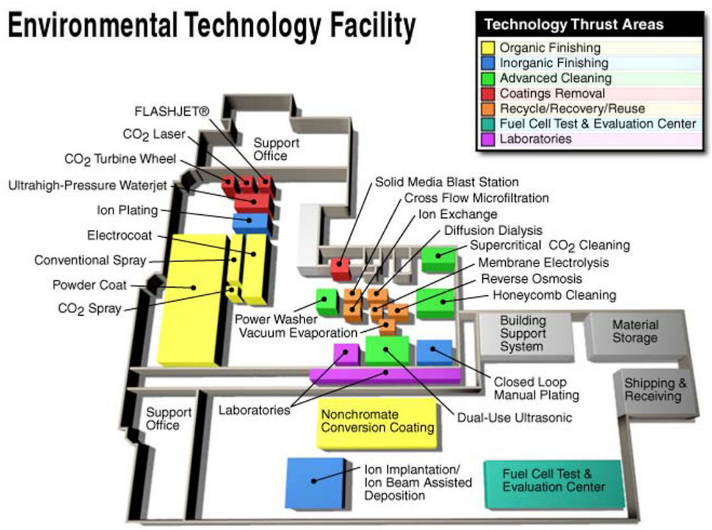
Points of Contact

- Tom Landy, TACOM-TARDEC, (586) 574-8818, LandyT@tacom.army.mil
- Bill Thomas, NSWCCD, (301) 227-5258, thomaswm@nswccd.navy.mil
- Richard Eichholtz, ODASA(ESOH), COR, (410) 436-5910, dick.eichholtz@daapgea050.apgea.army.mil
- Mary Nelson, NDCEE, (904) 722-2509, nelsonm@ctcgsc.org
- Georgette Kotsagrelos, NDCEE, (412) 577-2655, kotsagre@ctcgsc.org

Applicable NDCEE Tasks

High-Pressure Waterjet Stripping of Tracked and Wheeled Vehicles (Task N.203)
Pollution Prevention Initiative (Task N.227, Mod 1)

TECHNOLOGY DEMONSTRATION FACILITY EQUIPMENT



NDCEE

the missing piece to today's environmental solutions

NDCEE Demonstration Facility

Located in Johnstown, Pennsylvania, the NDCEE Demonstration Facility is a venue for independent, third-party verification of environmentally beneficial technologies. In this real-life production environment, clients can try out, validate, and receive hands-on, in-depth training on new environmentally acceptable processes and materials before implementing them in their own facilities.

By using the Demonstration Facility, clients are able to reduce many of the technical and financial risks associated with implementing a new technology. For instance, the facility provides the DoD with the opportunity to select the best alternative by evaluating several state-of-the-art technologies in proof-of-principle demonstrations without shutting down their own production lines. Hardware and software can be tested before investments are made throughout the DoD. Client personnel can evaluate alternatives according to projected performance and cost factors, including equipment costs, start-up costs, throughput rates, operating costs and product quality. Alternatives may be commercially available technologies or custom-designed prototypes.

Once an alternative is selected, DoD personnel can use the facility to conduct a full-scale process validation under realistic operating conditions. In this way, the technology is evaluated against client standards to ensure that technical; production; costs; and environment, health, and safety requirements are satisfied. In the past, technologies were often implemented without proper evaluation and optimization, which often resulted in higher costs, especially if the technology was ill suited and had to be replaced. All testing is performed in accordance with approved test plans.

The Demonstration Facility is built based on an understanding of end-user needs. It is designed to provide flexibility, modularity and consideration of human factors. It integrates pollution prevention concepts to provide a fully self-contained operation. The facility includes quality control and device calibration laboratories, warehousing and maintenance areas, worker facilities, and a complete utility infrastructure.

The Demonstration Facility currently houses approximately 20 commercial-scale production technologies in the areas of cleaning; stripping; vacuum coating; organic and inorganic finishing; electroplating; and recycle, recovery and reuse. To ensure that these technologies are state-of-the-art, the NDCEE keeps abreast of improvements in the technologies and provides recommendations to the Government for upgrades. These recommendations are based on existing knowledge and experience working with the DoD and industry and take into account the DoD's highest-priority environmental needs.

The following section contains a summary of each technology located in the Demonstration Facility. In addition to providing recommended upgrades based on current industry standards and DoD needs, each summary also provides an overview of the technology, its specifications, its benefits and advantages, its limitations and disadvantages, representative NDCEE tasks, and potential technology transfer applications. The current value of each technology also has been calculated based on a straightline depreciation method as referenced by IRS regulation 1.167. This information is provided to aid in determining whether or not upgrades to the technology are justified.

Finally, a table is provided for each summary identifying the Services' high-priority needs relating to that technology. The referenced codes for the U.S. Air Force and Navy were obtained from the DoD's Draft *Environmental, Safety and Occupational Health High Priority Environmental Technology Requirements Report*, dated April 2001. The U.S. Army's codes were obtained from the AERTA list, dated October 29, 2001.

Closed Loop Manual Plating Line

(Electroplating)

Overview

Environmental compliance costs are driving the metal plating industry to search for ways to reduce the volume and toxicity of its waste through "greener" plating processes and materials. The closed loop electroplating line located in the NDCEE Demonstration Facility reduces the volume of wastes associated with electroplating operations through source reduction, recycling and resource recovery. Counter-current rinsing and recovery technologies reduce wastewater from rinsing operations and their resulting F006 sludges.

The line, which is capable of operating under any condition necessary for general electroplating and electroless plating, is used to evaluate new electroplating processes, particularly those that use noncyanide process chemicals and replacement metals for hexavalent chromium and cadmium. Typical processes that are available for demonstration include noncyanide copper, acid and alkaline zinc nickel, electroless nickel, electroless nickel-boron, nickel-tungsten-silicon-carbide, nickel-tungsten-boron, and noncyanide silver. Each of these processes is evaluated for its engineering properties, environmental advantages, life-cycle cost and production readiness. The line can also be used to evaluate other new alternatives as they become available.

The Closed Loop Manual Plating Line is easily configurable to any special requirement of the user. Designed for rack and barrel processing, the line processes parts up to 2' x 2' x 1' in size and weighing up to 250 lbs. Electrocleaning and acid activation prepare the parts for plating. Four in-line plating stations can handle any type of plating solution. Each plating tank is separately bussed, filtered and heated. Temperature is automatically controlled at ±5°F. Each tank is equipped with both air and mechanical agitation. Fumes are exhausted from each tank through a packed bed scrubber with a mist eliminator prior to discharge. All scrubber water is also recycled.

The line is designed for near-zero water discharge. Multiple rinsing sequences (spray rinsing, double or triple counter flow, or a combination of these) minimize wastewater that requires treatment or disposal. All rinses are segregated and undergo a recycling process, such as microfiltration, reverse osmosis, or evaporation, depending on the specific electroplating process.

Specifications

The following table contains the specifications and parameters of the Closed Loop Manual Plating Line.

Closed Loop Manual Plating Line Specifications and Operating Parameters

Specification	Parameter
Maximum Part Size	2' x 2' x 1'
Maximum Part Weight	250 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Closed Loop Manual Plating Line.

Original Purchase Cost and Current Value of the Closed Loop Manual Plating Line

Purchase Cost	Current Value	Years of Service
$190,400	$79,333	7

Technology Benefits and Advantages

- High-quality parts can be obtained without generating wastes.
- Hardness, lubricity, fatigue and corrosion resistance of the coating can be optimized by varying bath operating parameters such as time, temperature, current density and solution concentration.
- The equipment is reconfigurable to demonstrate a variety of processes.
- The equipment reduces the volume of wastes associated with electroplating through source reduction, recycling and resource recovery.
- Counter-current rinsing and recovery systems in a closed loop plating line reduce wastewater from rinsing operations.
- The process is beneficial to the environment by reducing hazardous waste.

Technology Limitations and Disadvantages

- Part sizes that can be processed are limited by the size of the plating tanks.

Recommended Upgrades for Continued DoD Support

The Closed Loop Manual Plating Line currently meets or exceeds modern industry standards. The equipment is maintained in operational condition. Currently, there are no recommended or required upgrades to the system.

Representative NDCEE Tasks

Environmental Metal Plating Alternatives - Electroless Nickel Plating Rejuvenation (Task N.089)

- Evaluated technologies capable of reducing the amount of waste generated by electroless nickel plating processes

Evaluation of Noncyanide Silver Plating (Task N.104)

- Evaluated commercially available noncyanide alternatives to silver plating processes

Materials and Process Partnership for Pollution Prevention/Pollution Prevention Initiative (Task N.227)

- Evaluated commercially available noncyanide alternatives to copper and silver plating processes

Alloy Plating to Replace Cadmium on High-Strength Steels (Task N.000-02, Subtask 7)

- Evaluated commercially available noncyanide alternatives to cadmium plating processes

Potential Technology Transfer Applications

This technology could be applied in those applications that are looking to reduce waste and/or identify environmentally friendly alternatives through electroplating and electroless plating.

DoD Need

Army: CM-4

Navy: 2.I.01.g, 2.I.01.q, 3.I.03.b, 3.I.03.e, 3.I.11.b, 3.I.13.a

Closed Loop Manual Plating Line

CO_2 Pellet Blaster and Turbine Wheel

Overview

Carbon dioxide (CO_2) blasting is an alternative process to chemical cleaning and stripping. The obvious advantage of CO_2 blasting over chemical stripping is that the inert media (CO_2) dissipates. There are two basic types of CO_2 blasting systems: pellet blasting for heavy cleaning and snow blasting for precision cleaning.

CO_2 pellets are uniform in shape. The effectiveness of the pellets as a blast medium is similar to abrasive blasting media. However, the pellets do not abrade metallic substrates. This process can be used for cleaning, degreasing, some depainting applications, surface preparation, and deflashing (flashing is the excess material formed on the edges of molded parts).

The process starts with liquid CO_2 stored under pressure (~400 psig). The liquid CO_2 is fed to a pelletizer, which converts the liquid into solid CO_2 snow (dry flakes) and then compresses the snow into pellets at about -110°F. The pellets are metered into a compressed air stream and applied to a surface by manual or automated cleaning equipment with specially designed blasting nozzles. The CO_2 pellets are projected onto the target surface at a high speed. As the dry ice pellets strike the surface, they induce an extreme difference in temperature (thermal shock) between the coating or contaminant and the underlying substrate, weakening the chemical and physical bonds between the surface materials and the substrate. In addition, there is mechanical impact or abrasion. Immediately after impact, the pellets begin to sublimate (vaporize directly from the solid phase to a gaseous phase), releasing CO_2 gas at a very high velocity along the surface to be cleaned. The high velocity is caused by the extreme density difference between the gas and solid phases. The kinetic energy that is produced dislodges the contaminants (coating systems, contaminants, flash, etc.) resulting in a clean surface. Variables that affect process optimization include the following: pellet density, mass flow, pellet velocity and propellant stream temperature.

DoD Need

Army: CM-3, P2-1

Air Force: 120, 225, 814, 988, 1468, 1232

Navy: 2.I.01.g, 3.I.05.a

CO_2 pellet blasting is effective in removing some paints, sealants, carbon and corrosion deposits, grease, oil and adhesives as well as solder and flux from printed circuit board assemblies. This process also provides excellent surface preparation prior to application of coatings or adhesives and is suitable for most metals and some composite materials. However, thin materials may be adversely affected. Blasting efficiency is approximately equal to that of other blasting operations and can approach 1 ft^2/minute after optimization. CO_2 blasting can be done at various velocities: subsonic, sonic, and even supersonic. Therefore, equipment noise levels are high (95–130 dB). This operation always requires hearing protection.

CO_2 Pellet Blasting Operations System

Waste cleanup and disposal are minimized because only the coating or contaminant residue remains after blasting. There is no liquid waste because CO_2 pellets disintegrate. They pass from a solid to a gaseous state, leaving no spent media residue. With regard to toxic air control, small quantities of coating particles are emitted to the air. A standard air filtration system should be provided.

More durable pellets can be achieved using liquid nitrogen injection to cool the blasting air that transports the pellets to the nozzle. Higher pellet velocities or more durable pellets are required to effectively remove military coatings.

This "more aggressive" process shows the potential to cause peening, warping, and an increased cold working. This is especially evident on sheet aluminum less than 0.060" thick. The paint removal rate is also too slow for economical use.

Specifications

The following table contains the specifications and parameters for the CO_2 Pellet Blaster and Turbine Wheel.

CO_2 Pellet Blaster and Turbine Wheel Specifications and Operating Parameters

Specification	Parameter
Pelletizer	Alpheus Model 290
Pellet Blaster	Alpheus Model 45
Rotary Pellet Blaster	Cryogenics Applications F, Inc.
Rotary Blaster Robot	Fanuc 420 Robot
CO_2 Capacity	300–600 lbs. of 1/16" x 1/16" D pellets per hour
Accessories	Complete pellet blasting gun with hoses

Current Equipment Value

The following table contains the purchase cost and current equipment value of the CO_2 Pellet Blaster and Turbine Wheel.

Original Purchase Cost and Current Value of the CO_2 Pellet Blaster and Turbine Wheel

Purchase Cost	Current Value	Years of Service
$117,000	$48,750	7

Technology Benefits and Advantages

- Significantly reduces the amount of hazardous waste and hazardous air emissions generated compared to chemical stripping
- Reduces time required for cleaning/stripping processes by 80%–90%
- Leaves no residue on the component surface
- Is effective in precision cleaning
- Introduces no new contaminants

Technology Limitations and Disadvantages

- CO_2 blasting is not always a one-pass operation; an effective blasting operation usually requires multiple passes to achieve the desired effect.
- Operator training is required.
- CO_2 blasting can have high capital costs.
- Fixed position blasting operations can damage the component's surface.
- Solid waste is generated that contains coating chips that are potentially hazardous; media does not add to the volume of solid waste.
- Rebounding pellets may carry coating debris and contaminate workers and work area.

- Some soils (in cleaning operations) may redeposit on substrate.
- Nonautomated system fatigues workers quickly because of cold temperature, weight and thrust of blast nozzle. Automation (robotics) is required for full aircraft stripping operations.
- Potential hazard exists from compressed air or high-velocity CO_2 pellets.
- CO_2 blasting is not an effective paint removal process for aircraft. A production rate of 219 hours per aircraft (27 shifts) is not acceptable for the Air Force. The Air Force has developed a liquid nitrogen injection system to enhance the depainting operation that improves the strip rate. However, cost, reliability and complexity of the operation renders it unsuitable for production operation.

Recommended Upgrades for Continued DoD Support

There are currently no recommended upgrades required for the CO_2 Pellet Blaster and Turbine Wheel coatings removal equipment.

Representative NDCEE Task

Mobile Manipulation of a Carbon Dioxide Pellet Turbine Wheel (Task N.045)

- Evaluated the CO_2 pellet removal system on electrocoat, powder coat, chemical agent resistant coating, and nonskid coated surfaces
- Incorporated a flexible workcell design for use on a variety of parts

Potential Technology Transfer Applications

This technology is effective for removing oils and dust from hazardous shipping containers. In addition, it is effective in removing some paints, sealants, carbon and corrosion deposits, grease, oil and adhesives as well as solder and flux from printed circuit board assemblies.

Cross-Flow Microfiltration Units

(Kinetico Microfiltration Mobile Unit and Kinetico Bench-Scale Unit)

Overview

Microfiltration is a recycle/recovery technology generally used to remove solid particulate or emulsified contaminants from process solutions such as alkaline cleaning baths and electroplating/stripping bath rinses. Microfiltration can also be used to remove microorganism contamination from process solutions.

Microfiltration technology operates by use of a membrane system, in which the membrane material and pore size can be varied depending on the application. Pore sizes for microfiltration membranes range from 0.1–5 microns. Smaller pore-sized membranes, utilized in ultrafiltration techniques, range from 0.005–0.1 micron.

Cross-Flow Microfiltration is a filtration process in which the process fluid is passed through a filter membrane under pressure. The pressure of the passing fluid forces process fluid through the membrane pores, with the solid and emulsified materials remaining on the process side of the membrane. The fluid that is forced through the membrane is known as the permeate solution and is circulated to a holding tank. The remaining process solution with the solid contamination is circulated back to the process tank for additional passes through the filter membrane until the solids in the process fluid cause the pressure of the microfiltration system to climb and the process flow to drop considerably. At this point, the remaining solution is known as the concentrate.

The NDCEE Demonstration Facility contains both a full-scale and a bench-scale Cross-Flow Microfiltration Unit.

Specifications

The following table contains the specifications and parameters for the Cross-Flow Microfiltration Units.

Cross-Flow Microfiltration Specifications and Operating Parameters

Specification	Parameter
Flow Rate	Full-scale unit - 5 gpm Bench-scale unit - 0.5 gpm
Filter Porosity	0.005–0.8 microns
Pressure	65 psi
Membrane Material	Ceramics, teflon, polypropylene and other plastics
Material of Construction	PVC

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Cross-Flow Microfiltration Units.

Original Purchase Cost and Current Value of the Cross-Flow Microfiltration Units

Purchase Cost	Current Value	Years of Service
$250,000	$125,000	6 (for each unit)

Technology Benefits and Advantages

- Demonstrates wide array of process solutions
- Helps meet compliance with pretreatment standards for discharge regulations
- Helps meet effluent limits of NPDES permit
- Reduces waste volume by purifying and recycling contaminated water
- Reduces hazardous waste

Technology Limitations and Disadvantages

- Membranes can be costly and time-consuming to clean, depending on the solution to be recovered.

Recommended Upgrades for Continued DoD Support

Currently there are no recommended upgrades for the Cross-Flow Microfiltration Units housed in the NDCEE Demonstration Facility.

Representative NDCEE Tasks

Red River Army Depot Microfiltration Evaluation of Zinc Phosphate Solution (Task N.108)

- Evaluated microfiltration as an alternative technology to prolong the life of pretreatment baths
- Completed a cost analysis and an environmental impact comparison in relation to current processes

NDCEE Demonstration Projects - Alternative Cleaning Solution Recycle/Recovery (Task N.000-01, Subtask 5)

- Conducted bench-scale trials to recycle rust remover solutions

Potential Technology Transfer Applications

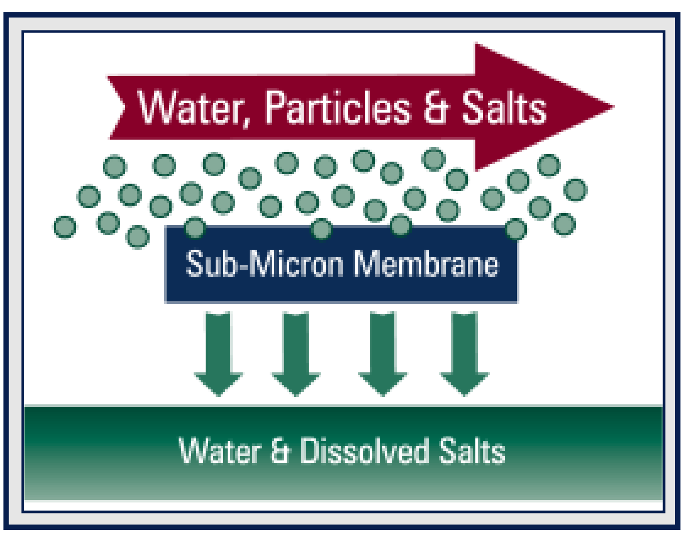
This technology could be applied in those applications that require the removal of solid particulate or emulsified contaminants from various types of process solutions.

DoD Need

Army: CM-7, CM-10

Navy: 3.I.03.b, 3.I.11.b, 3.I.11.j, 3.I.13.a, 3.III.06.d, 2.II.01.q

Air Force: 912



Microfiltration Process

Diffusion Dialysis Unit

(Kinetico Diffusion Dialysis Mobile Unit)

Overview

Diffusion Dialysis techniques are generally used to remove metals contamination from concentrated acid solutions. Common uses include recycling plating or stripping baths composed of sulfuric, nitric, phosphoric, or hydrochloric acids, or combinations of these acids and weak acids. A variety of metals can be removed or recovered, depending on the value of the metal. Some types of metals include zinc, iron, copper, chromium, nickel and silver.

Diffusion Dialysis functions by passing process fluid through a stack of semipermeable membranes. The unit housed in the NDCEE Demonstration Facility utilizes an anion permeable membrane, where the acid anions pass through the membrane to the low concentration, deionized water side of the membrane. The metals remain trapped on the high concentration side of the membrane, which contains the original process solution. The result of this process is an 80–95% recovery of the initial acid solution (somewhat diluted with deionized water) and 60–95% recovery of the metals.

Specifications

The following table contains the specifications and parameters of the Diffusion Dialysis Unit.

Diffusion Dialysis Unit Specifications and Operating Parameters

Specification	Parameter
Stack Size	2 liters/hour, 5 liters/hour
Membrane	Anion permeable

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Diffusion Dialysis Unit.

Original Purchase Cost and Current Value of the Diffusion Dialysis Unit

Purchase Cost	Current Value	Years of Service
Est. at $200,000	$100,000	6

Technology Benefits and Advantages

- Reduction of hazardous waste volume and the associated disposal costs
- Metals reclamation and reduction of liability if sludge is recovered by an outside company
- Lower annual cost for chemical makeup and replacement
- Improved production quality and consistent reproducibility of manufactured parts due to control of the metal ion concentration in the anodizing bath solution
- Beneficial to the environment by reducing hazardous waste
- More cost-effective than conventional treatment and discharge
- Units sized to fit any application

Technology Limitations and Disadvantages

- Moderately high capital cost
- Increase in the number of possible exposures with regard to the handling of hazardous waste

Recommended Upgrades for Continued DoD Support

The Diffusion Dialysis Unit currently meets or exceeds modern industry standards. The equipment is maintained in operational condition or in a state from which operation could be restored in less than one man-day. Therefore, there are no recommended or required upgrades to the system at this time.

Representative NDCEE Task

Evaluation of Adsorption Technology to Recover Contaminated Mineral Acid Solutions (Task N.064)

- Recovered mineral acid from iron contaminated hydrochloric acid solution

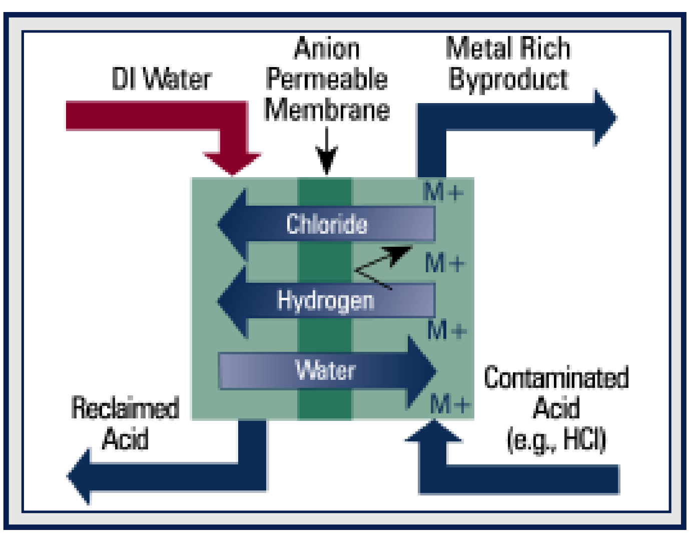
Potential Technology Transfer Applications

This technology could be applied in those applications that are looking to recover mineral acids from spent plating solutions and other concentrated acid stripping operations.

DoD Need

Army: CM-10

Navy: 2.III.01.b, 3.I.11.b, 3.I.13.a



Diffusion Dialysis Process

Dual-Use Ultrasonic System

Overview

The Dual-Use Ultrasonic System uses aqueous/semiaqueous solutions to clean and degrease a wide variety of parts. The system is comprised of five stainless steel tanks and a dryer. The stages include a wash station, emulsion rinse tank, three cascading water stages, and a “hot-air” dryer. The emulsion rinse, which may also be used for aqueous washing, and first water rinse tanks use ultrasonic and mechanical spray-under-immersion agitation to clean parts. Wash and rinse solutions can be recycled after filtration and oil clarification. Parts are rinsed in fresh or deionized water. Compressed air removes moisture from the parts before they are dried in the drying chamber.

Specifications

The following table contains the specifications and parameters of the Dual-Use Ultrasonic System.

Dual-Use Ultrasonic System Specifications and Operating Parameters

Specification	Parameter
Washing Temperature	80–180ºF
Rinse Temperature	80–180ºF
Dryoff Temperature	300ºF
Maximum Part Size	3' x 4' x 4'
Maximum Part Weight	250 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Dual-Use Ultrasonic System.

Original Purchase Cost and Current Value of the Dual-Use Ultrasonic System

Purchase Cost	Current Value	Years of Service
$506,000	189,750	7.5

Technology Benefits and Advantages

- May be set at various temperatures, pressures, cycle times and ultrasonic frequency settings for optimum performance
- Attains very high levels of cleanliness
- Removes small particles from small through-holes
- Removes debris from parts with complex geometries
- Decreases cleaning times over traditional immersion cleaning without ultrasonics

Technology Limitations and Disadvantages

- Not as effective as directed sprays for cleaning blind holes

Recommended Upgrades for Continued DoD Support

The Dual-Use Ultrasonic System currently meets or exceeds modern industry standards. The equipment is maintained in operational condition. Currently, there are no recommended or required upgrades to the system.

Representative NDCEE Task

Nonhalogenated Systems for Cleaning Metal Parts (Task N.007)

- Identified, tested, and evaluated environmentally compliant, technically and economically feasible nonhalogenated metal parts cleaning system

Potential Technology Transfer Applications

This technology could be applied in those applications looking to have large-scale contaminated surface areas cleaned with aqueous/semiaqueous solutions.

DoD Need

Navy: 2.I.01.g, 2.I.01.q, 2.I.01.s, 3.I.11.b, 3.I.13.a

Dual-Use Ultrasonic System

Electrocoating Line

Overview

Electrocoating (E-coat) is an electrodeposition process that applies specially formulated organic coatings to conductive substrates by means of an aqueous paint bath.

E-coat provides the substrate with exceptional corrosion protection and weatherability because of its ability to completely and uniformly coat all surfaces and deep recesses of complex-shaped parts. This capability allows the automotive, appliance, utility, and other high-volume industries to use E-coat extensively for precision application of primers and one-coat enamels. Coatings are applied to a wide variety of products, including agricultural equipment, furniture, automotive parts, wheels, electric transformers and switchgears, washing machines and dryers, microwave oven cavities, heating and cooling systems, and metal cans.

E-coat is environmentally friendly because it uses waterborne paints. Coatings contain 85–95% nonvolatile solids, excluding water. In addition, the E-coat Line in the NDCEE Demonstration Facility eliminates solid wastes by recycling process materials through closed-loop rinsing and ultrafiltration.

The E-coat process can coat up to 2,500 square feet of metal per hour. Its 95% minimum transfer efficiency and automated process cycles result in significant cost savings and productivity gains. Labor and material usages are reduced as well.

Parts to be electrocoated first pass through a cleaning/pretreatment subsystem to remove dirts, oils and drawing compounds. Depending on the application, either iron or zinc phosphate pretreatments can be applied for adhesion and/or corrosion protection, respectively. After pretreating and drying, parts enter the E-coat Line via an overhead conveyor and are lowered in and out of process tanks by indexing lifts.

The five-stage coating process begins with dip application of the coating in the main paint bath, or tank. Once coated, excess coating is removed by a series of rinses: a spray rinse, an immersion rinse, a second immersion rinse, and a final spray rinse with deionized water. Rinse waters are counterflowed and pass through a closed-loop, pressure-induced ultrafiltration system that separates the paint solids from the rinse water. The rinse water is then recycled into the main E-coat tank. This process conserves material, decontaminates the bath, and controls the paint performance. Parts are then conveyed to a thermal curing oven for curing.

Specifications

The following table contains the specifications and parameters of the E-Coat Line.

E-Coat Line Specifications and Operating Parameters

Specification	Parameter
Number of Stages	5
Capacity	2,500 ft^2/hr
Loads per Hour	1 to 20
Maximum Part Size	4' x 4' x 3'
Maximum Part Weight	250 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value of the E-coat Line.

Original Purchase Cost and Current Value of the E-coat Line

Purchase Cost	Current Value	Years of Service
$625,000	$234,375	7.5

Technology Benefits and Advantages

- Reduces environmental impacts associated with hazardous solvents and solid/hazardous waste generation and disposal over conventionally spray applied primers
- Applies a uniform coating of predetermined thickness over parts with simple or complex geometries, including sharp edges and points
- Eliminates runs and sags that are common with conventional dip or spray applications
- Can be used as an epoxy primer for most liquid or powder topcoats
- Offers many desirable coating characteristics such as abrasion and corrosion protection

Technology Limitations and Disadvantages

- The process is limited to one-coat application.
- Different colors require different processing tanks.
- Ventilation, after curing, is required until coated parts cool to 150°F.
- The part and conveyor carrier must be isolated from electrical ground.
- A chiller is required to maintain coating process bath temperature.
- The electrocoat tank requires daily checks by a trained chemist.
- Continuous maintenance is required for ultrafiltration system.
- Deionized water with an ultraviolet water disinfection treatment system is required in order to maintain bath integrity.
- Anolyte wastewater is generated as a waste stream.
- The periodic flushing of ultra filters will generate a sludge waste stream.

DoD Need

Army: CM-3, P2-5

Air Force: 1232, 438, 805

Navy: 2.I.01.f, 2.I.01.q, 3.I.04.e

Recommended Upgrades for Continued DoD Support

There are currently no required or recommended upgrades for the E-coat Line housed in the NDCEE Demonstration Facility.

E-Coat Line with Multiple Components Being Rinsed

Representative NDCEE Tasks

Unitized Coating Application Facility Electrocoat and Powder Coat (Tasks N.002, N.006, and N.046)

- Evaluated reduced VOC and HAP coating systems
- Performed a life-cycle cost evaluation for two facilities

Potential Technology Transfer Applications

The E-coat process equipment would be a candidate technology to be transitioned/implemented at any DoD facility that is currently focusing on implementing VOC-compliant coatings and reducing waste streams associated with the maintenance of ground vehicle components, aerospace components and a variety of composites.

FLASHJET®

Overview

The FLASHJET® system is a pulsed-optical energy decoating process. It uses a combination of high-intensity infrared energy generated by a high-intensity pulsed Xenon flash lamp and abrasion from a blast medium of carbon dioxide pellets. The paint is in effect charred and the residual particles are vacuumed and placed in a storage container.

Traditionally, coating removal activities were performed using chemical or dry abrasive techniques. Due to the use of toxic solvents, the generation of large amounts of solid waste, and the environmental, health and safety concerns associated with these conventional processes, alternative coating removal processes are being investigated. One such alternative is the FLASHJET® system.

The FLASHJET® process is a fully automated process that uses a manipulator robotic assembly to strip the coatings from large and small components. The stripper head contains a Xenon flash lamp that produces pulsed light energy to break the molecular bonds of the coating. A thin layer of the coating is essentially burned or pyrolyzed. Simultaneously, as the coating is being broken up and the pyrolyzing process is occurring, a dry ice pellet stream is sweeping away the residue while also cooling and cleaning the surface. The paint that is removed is vacuumed away by an effluent capture system, which consists of high efficiency particulate air (HEPA) filters and activated charcoal. The effluent capture system separates the ash from the organic vapors by removing the ash through HEPA filters, and the organic vapor through the activated charcoal. The only wastes produced by this process are spent HEPA filters, which are tested for hazardous waste (dependent on the coating removal) and disposed of accordingly.

The system has a stripping rate of approximately 270 square feet per hour and the Xenon lamp is guaranteed for 500,000 flashes, which is directly dependent on the power level at which the lamp is operated (typically 1 million flashes are obtained.)

Specifications

The following table contains the specifications and parameters for the FLASHJET®.

FLASHJET® Specifications and Operating Parameters

Specification	Parameter
Part Size	Approximately 5' x 6' x 6'
Stripping Head	6" Xenon flashlamp
Power Supply	208 VAC
Carbon dioxide pellitizer flow rate	300–600 lbs./hr
Effluent capture system series	Hepa filter —> large fan —> carbon filter —> disposal
Average strip rate	1 mil removed per FLASHJET® pass

Current Equipment Value

The following table contains the purchase cost and current equipment value of the FLASHJET®.

Original Purchase Cost and Current Value of the FLASHJET®

Purchase Cost	Current Value	Years of Service
Donated to the NDCEE by the Air Force	Not Applicable	5

Technology Benefits and Advantages

- Does not release hazardous or toxic emissions
- Removes paint from surfaces faster than conventional chemical or mechanical means
- Is operator-friendly
- Generates little annual waste
- Is capable of selective stripping

Technology Limitations and Disadvantages

- Large capital cost investment

Recommended Upgrades for Continued DoD Support

The FLASHJET® unit currently housed at the NDCEE Demonstration Facility does not meet industry standards. Upgrades to meet current industry standards include:

- Upgraded control system including computer and interface hardware
- Upgraded flash tube capability
- Upgraded environmental system.

Based on a similar upgrade proposal, the estimated costs for upgrading the FLASHJET® system is approximately $200,000.

Representative NDCEE Task

Tri-Service Demonstration and Validation of the Pulsed-Optical Energy Decoating FLASHJET® Process for Military Applications (Tasks N.126 and N.226)

- Demonstration and validation activities were conducted on CH-53 off-aircraft components
- An environmental cost analysis was conducted comparing FLASHJET® to Plastic Media Blasting.

Potential Technology Transfer Applications

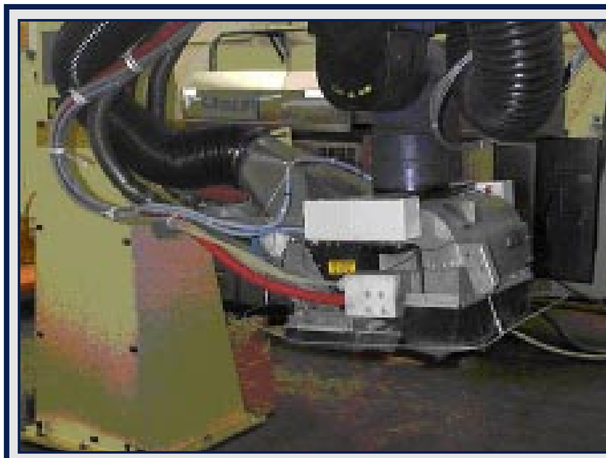
Transfer sites include facilities in all branches of the DoD that are currently utilizing abrasive and chemical methods to remove coatings.

DoD Need

Army: CM-4, CM-9

Air Force: 1232, 225, 311, 814, 988, 1468

Navy: 2.I.01.g, 3.I.05.a



FLASHJET® System

Fuel Cell

Overview

The generation of electricity is typically performed through the burning of fossil fuels in internal combustion engines (i.e., gasoline, Diesel, gas turbine) or in boilers to generate high-pressure steam that is supplied to a steam turbine. A fuel cell generates electricity through an electrochemical process similar to a battery. However, with a fuel cell, as long as fuel is supplied, electricity is continually produced.

The principles behind fuel cells have been known since 1839, but were not practically applied until the NASA Gemini program in the 1960s. With improvements in the technology and increasingly strict pollutant emissions regulations, fuel cells are a solution that is currently economical in some applications. The market for applications requiring electricity is extremely large and diverse, resulting in a heightened interest and development of fuel cells for applications ranging from mobile phones to vehicular power to utility power plants. It is expected that fuel cells will become commonplace during the next decade.

Fuel cells are generally more efficient in generating electricity than traditional methods while being scalable, meaning that the efficiency does not significantly change with size and power produced, unlike most traditional generating methods.

Several types of fuel cells are being developed for applications as small as a mobile phone (<1 Watt) to as large as a small power plant for an industrial facility or a small town (>10 Megawatts). The fuel cell tested under the NDCEE contract for the U.S. Army Engineer Research and Development Center (ERDC)/Construction Engineering Research Laboratory (CERL) is a PC25C, 200 kW Phosphoric Acid Fuel Cell (PAFC) manufactured by UTC Fuel Cells.

The PC25C is one of the first commercially available fuel cells in this size range. The ERDC/CERL supported the installation of 30 PC25Cs at military installations around the country to gain working experience with this new technology. Under the direction of ERDC/CERL, the NDCEE established a national capability, the Fuel Cell Test & Evaluation Center (FC*Tec*) for performing comprehensive, independent testing of fuel cell power plants. The PC25C shown below is located in the FC*Tec* site at the NDCEE Demonstration Facility.

Specifications

The following table contains the Specifications and Parameters for the PC25C Fuel Cell.

PC25C Fuel Cell Specifications and Operating Parameters

Specification	Parameter
Operating Temperature	-20–110ºF
Electrical Power Output	0–200 kWe
Thermal Power Output	>800,000
Fuel Cell Size	212" x 114" x 121"
Fuel Cell Weight	40,000 lbs.

Current Equipment Value

The following table contains the purchase costs and current equipment value of the PC25C Fuel Cell.

Original Purchase and Installation Costs and Current Value of the PC25C Fuel Cell

Purchase Cost	Current Value	Years of Service
$800,000	$566,667	3.5

Technology Benefits and Advantages

- Almost emission-free generation of electricity
- Quiet, modular units located very near where power is needed, including a remote site
- Has been shown to provide low-emission, premium-power electric generation as well as continuous uninterruptible power
- Provides useful thermal heat as a byproduct
- Can be operated with natural gas and other fuel blends
- Can be operated in grid-connected or grid-independent modes
- Can be installed successfully by typical contracting teams without specialized fuel cell experience

Technology Limitations and Disadvantages

- Technology is just emerging from development phase and into commercialization
- Currently more expensive than existing technologies
- Lack of trained professionals for service and maintenance

Recommended Upgrades for Continued DoD Support

Within the DoD, premium power applications are abundant. Uninterruptible power systems are used frequently. These systems often have requirements for long (over 1 hour) power capacity. In light of that, any premium power requirement could be analyzed for the implementation of fuel cells to improve the reliability of the system. Electrical distribution systems providing 99.9999% reliability have been installed using fuel cells combined with various other power technologies.

Current fuel cell systems are behind current commercial power generation standards because of their new market entry. However, constant improvements in the manufacturing and development of fuel cell systems is evening the playing field.

The fuel cell installation design should incorporate complete use of the recoverable heat to improve the overall system efficiency. This would allow for more efficient power production with the potential to eliminate environment contamination.

Representative NDCEE Tasks

ESTCP Validation Tasks (Task N.098)

- Investigated the uses of fuel cells in DoD applications
- Identified fuel cell applications not currently pursued by the DoD, including premium power, DC power and hydrogen source applications
- Reviewed the economics of fuel cell technology including cost comparisons to more conventional energy sources

U.S. Army ERDC/CERL Fuel Cell Technology Program (Task N.211)

- Provided testing and evaluations, in cooperation with various fuel cell manufacturer's power plants, with the focus to support life-cycle-cost reduction and performance improvement goals
- Provided the capability for independent design assessments of alternative technology fuel cell system configurations and components

DoD Need

Army: P2-7, CM-8

Navy: 2.I.01.b, 2.I.01.i

UTC Fuel Cells PC25C, 200 kW Phosphoric Acid Fuel Cell

Potential Technology Transfer Applications

The UTC Fuel Cells PC25C, 200 kW Phosphoric Acid Fuel Cell would be candidate technology to be implemented at any DoD facility that needs highly reliable, nearly emissions-free electrical power. This fuel cell could substitute for older technologies, such as batteries, as an uninterruptible power supply. Collocation of electrical power needs and thermal needs (e.g., hot water or low-pressure steam) will make any installations more economical. Additional applications include remote power production in which the fuel cell is the primary energy provider, not connected to the power grid.

Honeycomb Cleaning System

Overview

The Honeycomb Cleaning System was originally developed to clean aircraft honeycomb, but is suitable for difficult-to-clean parts that have strict cleaning requirements. Parts are positioned on a cart that is rolled along a track into the washer. A 385-nozzle spray bar moves back and forth beneath the parts, spraying a heated wash solution followed by a deionized water rinse. Overhead nozzles wash and rinse the top portion of the honeycomb. Wash and rinse solutions are then filtered and recycled. Compressed air removes excess water from the parts before they are dried by a high-capacity blower in a humidity-controlled oven.

Specifications

The following table contains the specifications and parameters of the Honeycomb Cleaning System.

Honeycomb Cleaning Specifications and Operating Parameters

Specification	Parameter
Part Size	6' x 6' x 4'
Part Weight	250 lbs.
Wash Temperature	80–180°F
Rinse Temperature	80–180°F
Dry off Temperature	300°F

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Honeycomb Cleaning System.

Original Purchase Cost and Current Value of the Honeycomb Cleaning System

Purchase Cost	Current Value	Years of Service
Donated to the NDCEE by the Air Force	Not Applicable	7

Technology Benefits and Advantages

- Aqueous/semiaqueous closed loop system that is good for replacing solvent cleaning
- Environmentally friendly

Technology Limitations and Disadvantages

- Designed for honeycomb cleaning (nozzles within the cabinet are set up for this application)
- Is not as versatile as some other types of aqueous cleaning systems

Recommended Upgrades for Continued DoD Support

The Honeycomb Cleaning System is not currently in operational condition. However, no upgrades to the system are recommended until such time as a need for the equipment is identified.

Potential Technology Transfer Applications

This technology could be used for applications that have difficult-to-clean parts with strict cleaning requirements such as aircraft honeycomb.

DoD Need

Army: CM-3, P2-1

Navy: 2.I.01.g, 3.I.11.b, 3.I.13.a, 3.II.03.a

Honeycomb Cleaning System

Ion Beam Assisted Deposition System

Overview

Most DoD repair facilities use "wet" processes to apply cadmium, chromium and other surface coatings to a variety of aerospace, tank, automotive and armament components. Cadmium and chromium are important metals because they impart essential physical and mechanical properties to the surface of the component being coated to extend its useful life. The use of traditional wet processes results in the generation of heavy metal wastes that require expensive treatment. The DoD and private industry have been searching for alternative processes that generate little or no waste, are environmentally acceptable and pose reduced exposure risks to operators. These alternative application technologies must meet stringent performance requirements while remaining technically and economically feasible.

Ion Beam Assisted Deposition (IBAD) is a coating process that incorporates both a means of physical vapor deposition (PVD) and simultaneous ion bombardment. During processing, the substrate surface is bombarded with positively charged ions while neutral species of the coating material are delivered concurrently to the substrate via a PVD technique such as thermal or electron beam evaporation, cathodic arc, or sputtering. IBAD typically operates at a pressure of approximately 10^{-4}–10^{-5} Torr, and typically utilizes low-energy ion bombardment with high beam current, high-energy ion bombardment with low beam current, or a moderate beam energy and current. The impinging ions provide nucleation sites for the neutral species, and at high energies, ion beam mixing can generate a physically mixed zone between the substrate surface and the coating, resulting in increased adhesion. Other benefits gained with this process include reductions in porosity and pinholes, and increased control of internal stress, morphology, density and composition.

The thickness of the coating is limited at present to deposits ranging up to several micrometers. The coating species can be virtually any element, compound or alloy that is capable of being vapor deposited. The gaseous ions may be either inert or reactive, (e.g., argon or nitrogen, respectively). Hard coatings of interest for wear applications generally include titanium nitride, chromium nitride, alumina and other ceramic coatings. These coatings generally are used for high-cost or value-added components. Substrates include metals, plastics, ceramics and glasses.

The NDCEE identified ion beam processing as an alternative to traditional electroplating technologies. The IBAD process generates minimal waste, poses very few health risks and can provide superior surface properties.

Specifications

The following table contains the chamber dimensional specifications for the IBAD System.

IBAD System Chamber Dimensional Specifications

Chamber Dimensions	Main Chamber	Extension	Load Lock
Length (inches)	72"	42.25"	48"
Diameter (inches)	72"	36"	36"

The chamber dimensions allow the IBAD unit to accommodate components up to 6' in length, 1' in diameter, and 2,000 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value for the IBAD System.

Original Purchase Cost and Current Value of the of IBAD System

Purchase Cost	Current Value	Years of Service
$ 1,980,000	$ 1,155,000	5

Technology Benefits and Advantages

- Generates minimal waste
- Reduces health risks
- Provides superior surface finishes with respect to the current processes in use
- Is more environmentally friendly than traditional coating processes

Technology Limitations and Disadvantages

- Specific technologies can impose constraints; for example, line-of-sight transfer makes coating components with a deep internal diameter practically impossible.
- System requires large initial capital investments.
- The means of manipulating parts can be expensive.

Recommended Upgrades for Continued DoD Support

The following upgrades are recommended for DoD support:

- Although the current IBAD equipment that is located at the NDCEE Demonstration Facility is considered to be state-of-the-art technology, it would be beneficial for this equipment to have a planetary gear fixture installed. This would provide the following benefits to the equipment:
  - Ability to coat multiple, complex-shaped components
  - Ability to treat more parts in a single trial, making the process more cost effective
  - Improvements in base materials for parts that cannot be coated due to dimensional constraints.
- A commercial-off-the-shelf (COTS) moderate energy ion source may increase the reliability of the process by decreasing lead times regarding maintenance. Currently, the moderate energy ion source that was provided with the IBAD system is a custom design. As such, minor maintenance issues require increased attention and longer solution times.
- The addition of other means of physical vapor deposition (e.g., cathodic arc or sputtering sources) to improve deposition rates and enable a wider range of materials to be evaporated would provide benefits. Difficulties are often presented with limitations on energy input to the material to obtain a satisfactory deposition rate (this also leads to better economics). This is a problem with high melting point materials or materials with

DoD Need

Army: P2-6, P2-11

Air Force: 805, 608, 613

Navy: 3.I.03.b, 3.I.04.h

Ion Beam Assisted Deposition Chamber

a high thermal conductivity (Aluminum is cooled by the crucible walls as it is being heated unless a crucible liner is used. These can be expensive and crack once the melt cools and the material expands.)

- The addition of a metal ion source to enable metal ion implantation into substrate materials for improved hardness and wear resistance would be beneficial. As such, materials that do not form nitrides, such as nickel, could be treated.
- New cryopumps with quicker adsorption rates for gases, such as those manufactured by CTI Cryogenics, would benefit this equipment.

Representative NDCEE Tasks

Ion Beam Processing for Environmentally Acceptable Coatings (Task N.001)

- Gathered baseline data regarding current components, such as landing gear, pistons, and cylinder assemblies, that are refurbished with electroplated cadmium and chromium
- Identified ion beam processing methods as potential alternatives to electroplated cadmium and chromium
- Designed the ion beam system based upon the baseline information gathered

Sustainable Green Manufacturing (Tasks N.213 and N.301)

- Developing life-cycle-based environmental improvements
- Conducting research in coatings development, corrosion prevention, environmental engineering

Materials and Processes Partnership for Pollution Prevention (Task N.227)

- Investigating non-line-of-sight chromium alternatives
- Evaluating ion beam and plasma-based alternatives to chrome plating of gas turbine engines
- Evaluating noncyanide plating and stripping processes

Corrosion Measurement and Control (Tasks N.255 and N.304)

- Identifying and investigating environmentally friendly corrosion preventative technologies
- Conducting field testing on identified potential corrosion preventative technologies

Potential Technology Transfer Applications

Currently, the process is being investigated for use on a variety of weapons systems. If the coatings and surface finishing methods are found to be technically and economically feasible, implementation may follow. Some of these weapon systems include:

- Line-haul truck pins and cam-followers - Holland Hitch
- M1 intermediate and anti-friction, bearing housings - ANAD
- Helicopter drive shafts and gear scuff samples - Boeing Mesa
- M2A2 (Bradley) output carriers and transmission bearing assemblies (races and bearings) - RRAD
- DDC series 60 engine valve stems and seats - Eaton
- Diesel water pump seals
- Boeing outer diameters of rings
- Bearing hubs - ANAD and TACOM
- A29E3 artillery rounds: Depleted uranium (DU) penetrators and graphite sabots - ARDEC, Alliant
- Duo cone seals for Marine Amphibious Assault Vehicle - General Electric (GE)
- Test coupons for the preliminary corrosion testing for GTE components - GE
- M1A1 bearing cups - ANAD
- AGT 1500 main engine bearings - ANAD
- B-2 bomber bomb door hinge - Boeing

Ion Exchange Units

(Kinetico Ion Exchange Mobile Unit and Kinetico Bench-Scale Ion Exchange Unit)

Overview

Ion Exchange technology can be utilized for many purposes. It is often used for polishing drinking water or wastewater for discharge, removing contaminant metal ions from rinsewaters and dilute etching solutions, recovering mineral acids from spent electroplating solutions (efficiencies of >95%), and removing organic contamination from a variety of water sources.

Ion Exchange functions by performing an actual exchange of ionic species between the resin and the process solution. The resin is uniformly charged, either positive or negative, with an oppositely charged ion attached to the resin (generally hydrogen ion or hydroxyl ion). When the process solution is passed over the resin, the resin exchanges the hydrogen or hydroxyl for the more strongly charged contaminant ion. Resin materials can be composed of strong base anionic (SBA) materials, weak base anionic (WBA) materials, strong acid cationic (SAC) materials, weak acid cationic (WAC) materials, various chelating agents, mixed bed resins (both cationic and anionic), or granular activated carbon (GAC) for organic contaminant removal.

The NDCEE Demonstration Facility has both full-scale and bench-scale units that can be configured with any of the above resin materials or combinations of resins, such as an anionic resin bed, followed by a cationic resin bed, with a GAC bed for polishing at the end.

Specifications

The following table contains the specifications and parameters of the Ion Exchange Units.

Ion Exchange Units Specifications and Operating Parameters

Specification	Parameter
Flow Rate	Full-scale unit - 1 gpm Bench-scale unit - 0.1 gpm
Resin	SBA, WBA, SAC, WAC, GAC, various chelating
Resin Beds	4, sequential
Material of Construction	CPVC

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Ion Exchange Units.

Original Purchase Cost and Current Equipment Value of the Ion Exchange Units

Purchase Cost	Current Value	Years of Service
$250,000	$125,000	6 (for each piece)

Technology Benefits and Advantages

- Helps meet compliance with strict discharge regulations
- Reduces chemical costs and waste volume by purifying and recycling contaminated water
- Improves water quality
- Lowers operating costs for waste treatment and capital costs for chemicals
- Reduces hazardous waste
- Has compact design for efficient use of space

Technology Limitations and Disadvantages

- Some resins can be expensive.
- Presence of contaminants (e.g., oil and grease, oxidants, acidity) may impact resin selection or require filtration prior to ion exchange.

Recommended Upgrades for Continued DoD Support

The full-scale and bench-scale Ion Exchange Units are maintained in a state from which operation could be restored in less than one man-day. Therefore, there are no recommended or required upgrades to the units at this time.

Representative NDCEE Tasks

U.S. Navy - Evaluation of Adsorption Technology to Recover Contaminated Mineral Acid Solutions (Task N.064)

- Tested acid recovery from a wide range of simulated waste acid streams

Office of Industrial Technology Program Coordination (Task N.133)

- Demonstrated the ability to regenerate a spent anion exchange resin bed
- Determined the breakthrough point and optimum processing conditions by running a plating solution through the bench-scale unit

NDCEE Demonstration Projects - Alternative Cleaning Solution Recycle/Recovery (Task N.000-01, Subtask 5)

- Evaluated more environmentally friendly alternatives to alkaline rust removers

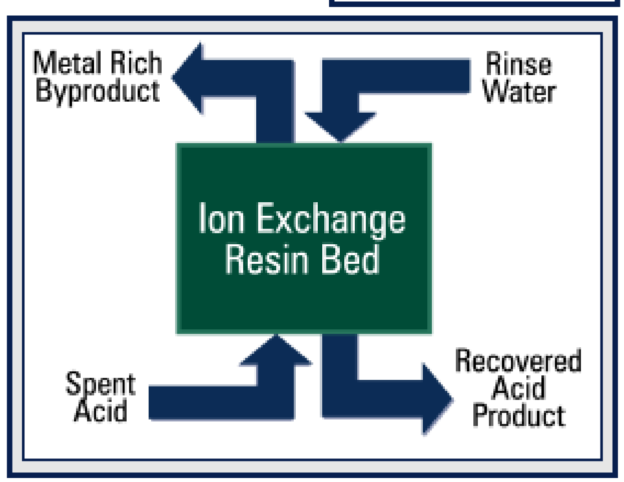
Potential Technology Transfer Applications

This technology could be applied in those applications that are looking to polish drinking water or wastewater for discharge, remove metals from rinsewaters and dilute etching solutions, recover mineral acids from spent electroplating solutions, and remove organic contamination from water sources.

DoD Need

Army: CM-7, CM-10, CM-5

Navy: 3.I.03.b, 3.I.11.b, 3.I.11.j, 3.I.13.a, 2.II.01.q



Ion Exchange Process

Ion Plating System

Overview

Ion Vapor Deposition (IVD), a specific subset of Ion Plating, of aluminum is a common vacuum coating process. The aluminum is used as a substitute for electroplated cadmium because it offers excellent corrosion resistance. A variety of other metals may be deposited by Ion Plating for applications requiring resistance to corrosion, wear or erosion.

Ion Plating is a physical vapor deposition (PVD) coating process in which the basic mechanism is an atom-by-atom transfer of material from the solid phase to the vapor phase and back to the solid phase, gradually building a film on the surface to be coated. The three fundamental steps of Ion Plating include:

1. Vapor phase generation from coating material stock by:
   - Evaporation (resistive or electron beam),
   - Sputtering, and
   - Cathodic arc.
2. The transfer of the vapor phase from source to substrate (evaporant transition) by:
   - Line-of-sight
   - Molecular flow
   - Vapor ionization by applying a bias to the substrate to attract the ionized material.
3. Deposition and film growth on the substrate.

These steps can be independent or superimposed on each other depending on the desired coating characteristics. The final result of the coating/substrate composite is a function of each material's individual properties, the interaction of the materials, and any process constraints that may exist.

DoD Need

Air Force: 805

Navy: 3.I.03.e, 3.I.04.h

Army: P2-6

The selection criteria for determining the best method of Ion Plating is dependent on several factors:

- Material to be deposited
- Rate of deposition required
- Limitations imposed by the substrate such as the maximum deposition temperature, size and shape
- Coating adhesion to the substrate
- Throwing power [(rate and thickness distribution of the deposition process, (i.e., the higher the throwing power, the better the process ability to coat irregularly shaped objects with uniform thickness)]
- Purity of coating materials
- Equipment requirements and their availability
- Cost
- Ecological considerations
- Abundance of deposition material

Ion Plater

Ion Plating is a desirable alternative to electroplating. Ion Plating can be applied using a wide variety of materials to coat an equally diverse number of substrates. The application of Ion Plating surface coating technologies at large-scale, high-volume operations will result in the reduction of hazardous waste being generated when compared to electroplating and other metal finishing processes that use large quantities of toxic and hazardous materials.

Specifications

The following table contains the specifications and parameters of the Ion Plating System.

Ion Plating System Specifications and Operating Parameters

Specification	Parameter
Chamber size	6' diameter x 12' length
Sample size	4' width x 7' length x 16" height maximum

Current Equipment Value

The following table contains the purchase cost and current equipment value for the Ion Plating System.

Original Purchase Cost and Current Value of the Ion Plating System

Purchase Cost	Current Value	Years of Service
$1,150,000	$479,169	7

Technology Benefits and Advantages

- This technology does not require hazardous materials nor does the process generate hazardous wastes.
- Reduction of hazardous waste helps facilities meet the requirements of waste reduction under RCRA, 40 CFR 262, Appendix, and also may help facilities reduce their generator status and lessen the amount of regulations (i.e., record keeping, reporting, inspections, transportation, accumulation time, emergency prevention and preparedness, emergency response) that they are required to comply with under RCRA, 40 CFR 262.
- By choosing appropriate materials and appropriate methods of Ion Plating, coatings can be produced to provide abrasion and corrosion resistant surfaces.
- Ability to utilize virtually any type of inorganic and some organic coating materials on an equally diverse group of substrates and surfaces using a wide variety of finishes is beneficial.
- This technology uses considerably less water than the traditional electroplating operations, as required under EO 12902, Energy Efficiency and Water Conservation at Federal Facilities.
- Has numerous applications to aerospace, tool, automotive, home appliance, hardware, jewelry, and other parts that require coatings for protection, aesthetic appeal, or both.
- More than one technique can be used to deposit a given film.

Technology Limitations and Disadvantages

- Temperature constraints may limit the degree to which dense coatings can be deposited on some plastics.
- It is difficult to find a corrosion resistant and lubricant in one coating.
- Specific technologies can impose constraints; for example, line-of-sight transfer makes coating annular shapes difficult, if not impossible.

- If high biases are being used, areas of the chamber can get hot to the touch and aspects of the chamber require cooling. This requires operator monitoring to ensure that water cooling continues throughout the deposition.
- Selection of the best technology may require experience and/or experimentation.
- This technology requires a cooling water system to dissipate large heat loads.
- This technology has high capital costs.

Recommended Upgrades for Continued DoD Support

This system recently has been upgraded. However, the sputtering sources and the program for the sputtering sources and the cathodic arc could be upgraded.

Representative NDCEE Tasks

Sustainable Green Manufacturing (Task N.213)

- Developing life-cycle-based, environmental improvements in coatings and corrosion prevention
- Testing alternative finishes on DoD components for improved wear and corrosion protection

Materials and Processes Partnership for Pollution Prevention/Pollution Prevention Initiative (Task N.227, Mod 1)

- Demonstrating the efficacy of the proposed environmentally friendly materials/ processes in both bench-scale and full-scale testing
- Validating alternative technologies prior to implementation

Corrosion Measurement and Control (Task N.255)

- Identifying, investigating, and developing environmentally friendly technologies to measure, control, and prevent corrosion
- Designing a corrosion service center prototype

Potential Technology Transfer Applications

This technology could be applied to those applications searching for an environmentally preferred alternative to traditional wet surface finishing processes such as electroplating. Other applications include parts that require improved engineering properties.

Liquid Coatings Application Equipment

(Conventional Spray)

Overview

The Liquid Coatings Application Equipment in the NDCEE Demonstration Facility consists of two open-face, cross-draft, paint spray booths (approximately 8' x 3' x 10'). The spray booths are designed with a triple combination of over-spray filters that minimize the size and amount of the particulate reaching the exhaust plenum. This keeps the exhaust duct and plenum very clean and virtually eliminates particulate emissions. Liquid spray equipment presently consists of several conventional air atomizing and HVLP applicators, air assisted-airless application equipment, and a high-volume, low-pressure (HVLP) turbine heated air spray system.

Specifications

The following tables contain the specifications and parameters of the Liquid Coatings Application Equipment.

Conventional Air Atomizing Applicators Specifications and Operating Parameters

Specification	Parameter
Operating Temperature	60–90°F
Operation Pressure	20–60 psi
Flow Rate	75–250 cc/min
Maximum Part Size	4' x 6' x 3'
Maximum Part Weight	250 lbs.

HVLP Applicators Specifications and Operating Parameters

Specification	Parameter
Operating Temperature	60–90°F
Operation Pressure	7–20 psi
Flow Rate	125–400 cc/min
Maximum Part Size	4' x 6' x 3'
Maximum Part Weight	250 lbs.

Air Assisted-Airless Applicator Specifications and Operating Parameters

Specification	Parameter
Operating Temperature	40–90°F
Operation Pressure	800–3000 psi
Flow Rate	400–1000 cc/min
Maximum Part Size	4' x 6' x 3'
Maximum Part Weight	250 lbs.

Turbine-Heated Air HVLP Applicator Specifications and Operating Parameters

Specification	Parameter
Operating Temperature	90–135°F
Operation Pressure	6–20 psi
Flow Rate	125–400 cc/min
Maximum Part Size	4' x 6' x 3'
Maximum Part Weight	250 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Liquid Coatings Application Equipment.

Original Purchase Cost and Current Value of the Liquid Coatings Application Equipment

Applicator	Purchase Cost	Current Value	Years of Service
Conventional air atomized	$ 500/gun	$ 167/gun	8
HVLP	$ 450/gun	$ 200/gun	8
Air assisted-airless	$ 4,000	$ 2,333	5
Turbine heated air HVLP	$ 42,000	$ 28,000	4

DoD Need

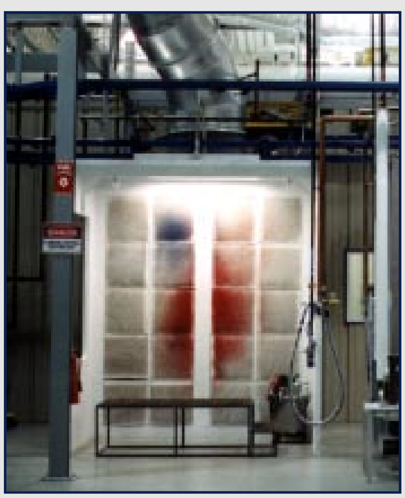
Army: P2-3, P2-1, CM-3

Navy: 2.I.01.q, 2.I.01.g

Air Force: 427

Technology Benefits and Advantages

- Inexpensive application equipment
- Minimal training needed to use applicators
- Easy to clean-up and maintain application systems
- Will handle a wide variety of coating formulations
- Requires only compressed air (clean) utility
- Requires minimal storage space



Conventional Spray Booth

Technology Limitations and Disadvantages

- Current booth size limits ability to coat larger parts and surfaces to demonstrate newer application technologies.
- Booth size limits material choice (i.e., isocyanates) due to limited air drawing power.

Recommended Upgrades for Continued DoD Support

State-of-the-art manually controlled, enclosed generator electrostatic applicators would provide enhanced transfer efficiency and surface finish quality required for most Air Force finishes. Using higher transfer efficiency applicators might allow for coating formulations with less HAP-containing solvents.

Lower-cost, portable turbine heated air HVLP cup gun systems would provide demonstration of higher-transfer efficiency HVLP application with portability required by most large depot maintenance activities and at DoD original equipment manufacturer (OEM) facilities.

Construction of larger coating area (20' x 10' x 10') with a state-of-the-art filtration triple filter bank with VFD driven fan exhaust for maximum ventilation would provide capability to coat larger structures typical of most depot maintenance shops.

Representative NDCEE Tasks

Paint Handling and Spraying Equipment Testing, Evaluation, and Training (Task N.023)

- Utilized as baseline for comparison with alternative coatings application technologies

Environmental Technology Verification Coatings and Coating Equipment Program (Tasks N.100, N.208, and N.306)

- Per EPA Standards, conventional coatings systems are utilized as a baseline when evaluating alternative coatings technology and equipment.

Potential Technology Transfer Applications

All DoD facilities that are currently utilizing conventional coatings technologies to maintain small- to medium-sized components and are in need of additional production capabilities would be potential transfer sites for this equipment.

Membrane Electrolysis Units

Overview

Membrane Electrolysis is an electrochemical process used to attract oppositely charged particles in solution across a semipermeable membrane. This process can be used to remove metal ion contamination from rinse waters and finishing baths utilized in etching, anodizing and stripping processes. The technology can also be used to reoxidize metal finishing baths and separate acids or bases, causing salt precipitation.

Membrane Electrolysis can function by two-compartment or three-compartment methods. For the two-compartment method, the positively charged anode is placed in one chamber and the negatively charged cathode in the other. Either a cation-permeable or anion-permeable membrane is placed between the two chambers. The process solution is then added to the appropriate chamber to achieve the desired type of separation. A voltage is applied to the electrodes and separation proceeds. The three-compartment system has a chamber for the process fluid in the center, with a semipermeable membrane on either side of the chamber. The cation chamber and anion chamber are then on opposite sides of the process chamber, with separation occurring by ions traveling from the process solution, through the membranes, to either outside (cation or anion) chamber.

The NDCEE Demonstration Facility contains a full-scale two-compartment unit, a full-scale three-compartment unit, and a bench-scale unit that can be configured as either two or three compartments.

Specifications

The following table contains the specifications and parameters for the Membrane Electrolysis Units.

Membrane Electrolysis Units Specifications and Operating Parameters

Specification	Parameter
Rectifier Rating	20v, 150 amp maximum
Membrane Size	1 ft^2 each
Membrane	Cation, anion permeable
Compartments	2 or 3
Anode Material	DSA, Pt/Ti, or other
Material of Construction	PVDF

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Membrane Electrolysis Units.

Original Purchase Cost and Current Value of the Membrane Electrolysis Units

Purchase Cost	Current Value	Years of Service
$250,000	$104,167	7

Technology Benefits and Advantages

- Helps meet compliance with strict discharge regulations
- Reduces chemical costs and waste volume by purifying and recycling contaminated water
- Improves water quality
- Lowers operating costs for waste treatment and capital costs for chemicals
- Reduces hazardous waste

Technology Limitations and Disadvantages

- Somewhat slow process/batch process
- An electrical process, which may generate noxious fumes
- Nodes and membranes need to be periodically replaced or stripped

Recommended Upgrades for Continued DoD Support

The full-scale and bench-scale Membrane Electrolysis Units are maintained in a state from which operation could be restored in less than one man-day. Therefore, there are no recommended or required upgrades to the units at this time.

Representative NDCEE Task

Office of Industrial Technology Program Coordination (Task N.133)

- Recovered rinse waters from oxalic acid solution for reuse

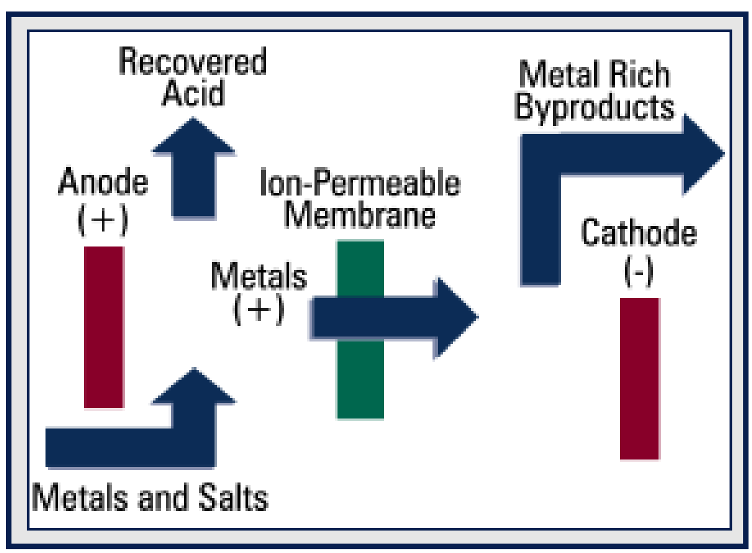
Potential Technology Transfer Applications

This technology could be applied in those applications that are looking to have metal ions and impurities recovered from rinse waters and finishing baths. These industries include various plating operations, precious metals recovery, and general cleaning/derusting operations.

DoD Need

Army: CM-7, CM-10, CM-5

Navy: 3.I.03.b, 3.I.11.b, 3.I.11.j, 3.I.13.a, 2.II.01.q



Membrane Electrolysis Process

Nonchromate Conversion Coating System

Overview

The full-scale Nonchromate Conversion Coating (Prototype) System is a general-purpose aqueous solution-based pretreatment line. The system is capable of applying most currently available nonchromate conversion coating chemistries and has the flexibility to apply newly developed ones as well.

The system is a linear design using a manual overhead conveyor to move parts from one processing tank to the next. The tanks are organized in stages, with each stage consisting of a process tank, a recirculation tank and two rinse tanks. Because the system was designed for optimum flexibility, any of these processing steps (alkaline clean, alkaline etch, acid etch, desmut, nonchromate pretreatment or sealant) may be omitted, modified, skipped or repeated as often as desired by the customer's and the processes' specific needs.

The Nonchromate Conversion Coating System was designed with the ability to apply pretreatment processes using either an immersion or spray application technique. Therefore, the customer can be provided with recommendations on whether spray application is viable, and if so, what the optimized parameters are such as spray time, concentration, temperature, etc. The system was also designed to be capable of both spray and immersion rinsing and comes equipped with fogging capability. This capability is generated by the use of special fog nozzles that are mounted within the processing and rinse tanks. The fog nozzles disperse water into a fine mist that gently causes condensation on the parts as they are being removed from a tank.

The system, as designed, contains tremendous flexibility and can evaluate any customer requirements in regards to processing parts and proving technical feasibility. The system was designed, however, to go one step further. Often when designing or evaluating processes, the concept of bath rejuvenation and maintenance is overlooked. This system was designed with quick-connect piping that can be used to individually attach any process tank with treatment technologies such as microfiltration, reverse osmosis, diffusion dialysis, membrane electrolysis, ion exchange or any other appropriate technique for maintaining and rejuvenating process solutions. This type of process maintenance can save a tremendous amount of raw material usage, waste generation, down time and non-conforming product by ensuring that the solution is always as pure as possible.

Specifications

The following table contains the specifications and parameters of the Nonchromate Conversion Coating System.

Nonchromate Conversion Coating System Specifications and Operating Parameters

Specification	Parameter
Number of Stages	6 (4 polypropylene, 2 stainless steel)
Maximum Part Size/Envelope	2' x 2' x 2'
Maximum Part Weight	250 lbs.
Operating Temperature Range	Polypropylene process tanks - ambient to 170°F Stainless steel process tanks - ambient to 200°F
Tank Capacity	Polypropylene process tanks - 175 gal. Stainless steel process tanks - 200 gal.

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Nonchromate Conversion Coating System.

Original Purchase Cost and Current Value of the Nonchromate Conversion Coating System

Purchase Cost	Current Value	Years of Service
$1,384,000	$865,000	4.5

Technology Benefits and Advantages

- Able to apply most currently available nonchromate conversion coatings
- Capable of both immersion and spray applications
- Capable of rejuvenating process baths using treatment technologies
- Can test and evaluate alternative pretreatments at full scale prior to implementation

Technology Limitations and Disadvantages

- Maximum part size of 2' x 2' x 2'
- Maximum part weight of 250 pounds

Recommended Upgrades for Continued DoD Support

The Nonchromate Conversion Coating System is currently able to process most available nonchromate conversion coating chemistries. The equipment is maintained in operational condition, or in a state from which operation could be restored in less than one man-day. Therefore, there are no recommended or required upgrades to the system at this time.

Representative NDCEE Tasks

Evaluation of Nonchromate Conversion Coating (Task N.008)

- Designed and built a system to evaluate, at full scale, potential nonchromate alternatives

Organosilane Pretreatment of Aluminum Alloys (Task N.095)

- Evaluated the performance of a nonchromate organosilane aluminum alloy pretreatment

Testing Services to Support the Development of Polyelectrolyte-Modified Zinc Phosphate Conversion Coatings for U.S. Army Tank-Automotive and Armaments Command (Task N.119)

- Conducted a full-scale demonstration of a modified zinc phosphate conversion coating process

Organosilane Pretreatment Process for Aluminum Alloys for U.S. Army Tank-Automotive and Armaments Command (Task N.295)

- Investigating other application methods for an organosilane pretreatment
- Providing field-level coordination for the implementation of a nonchromate conversion coating

Potential Technology Transfer Applications

The Nonchromate Conversion Coating System equipment would be a candidate technology to be transitioned/implemented at any DoD facility that is currently using chromate conversion coatings and for which a nonchromate pretreatment has been identified that meets the requirements of the application.

As a demonstration system, the Nonchromate Conversion Coating System decreases the risk involved in implementing nonchromate conversion coating alternatives. The system provides a testbed that presents minimal capital or financial risk to the DoD. This allows for a comfortable, confident transition of technology from the vendor to the DoD.

DoD Need

Army: CM-3, P2-3, P2-5, P2-1

Air Force: 805, 1261

Navy: 2.I.01.g, 2.I.01.q, 3.I.04.h, 3.I.13.a, 3.II.04.a

Nonchromate Conversion Coating System

Organic Finishing Powder Coating Line

Overview

Powder coating is an environmentally friendly coating process that can be used on a wide assortment of products from bullets to park benches. It provides a durable coating and reduces operating costs while eliminating volatile organic compounds (VOCs), hazardous air pollutants (HAPs) and solvent usage. The four basic powder coating methods are electrostatic spraying, conventional fluidized bed, electrostatic fluidized bed, and flame spray. Electrostatic spraying is the most commonly used powder coating application method. For all application methods, high-quality surface preparation (i.e., cleaning and conversion coating) is required to develop good coating adhesion to the substrate. Characteristics of the four different powder application techniques are described below.

In electrostatic spraying, an electrical charge is applied to the powdered coating particles while the part to be painted is electrically grounded. The applicator and grounded work piece create an electrostatic field that attracts the coating particles to the work piece. The coating particles that are deposited on the work piece retain some of their electrostatic charge, which holds the powder to the work piece. The coated work piece is placed in a curing oven, where the paint particles melt onto the surface and form a continuous film. Due to its versatility, this is the powder coating application method currently employed at the NDCEE Organic Finishing Powder Coating Line. In addition, the finishing line has the ability to apply three types of chemical conversion pretreatments to steel and aluminum parts in order to provide adequate adhesion for powder coatings. Automated conveying and a batch load, curing oven allow for maximum process control in the handling and thermal curing of the powder coated parts.

In a conventional fluidized bed applicator, powder particles are kept in suspension by an air stream in an engineered dip tank or “bed”. A preheated work piece is placed in the fluidized bed where the powder particles contact with the work piece, melt, and adhere to the surface. Coating thickness is dependent on the temperature and heat capacity of the work piece and residence time in the fluidized powder cloud. Further heating is generally not required when applying thermoplastic powder coatings. However, oven curing is required to cure thermoset powder coatings completely.

Electrostatic fluidized beds are similar in design to conventional fluidized beds, but the air stream is electrically charged as it enters the bed. The ionized air charges the powder particles as they move upward in the bed, forming a cloud of charged particles. The grounded work piece is covered by the charged particles as it enters the chamber. No preheating of the work piece is required; however, curing of the coating is necessary. This technology is most suitable for coating small objects with simple geometry.

The flame spray technique was recently developed for application of thermoplastic powder coatings. The thermoplastic powder is fluidized by compressed air and fed into a flame spray gun where it is injected through a flame of propane, melting the powder. The molten coating particles are deposited on the work piece, forming a film upon solidification. Rapid solidification does not allow a smooth film to develop so this technique is not suitable for high-aesthetic surfaces. Because no direct heating of the work piece is required, this technique is suitable for applying coatings to most substrates. Metal, wood, rubber and masonry can be coated successfully using this technique. This technology is also suitable for coating large or permanently fixed objects.

Powder coatings fall into two basic categories—thermoplastic and thermosetting. The choice of powders is dependent on the end-use application and desired properties. Generally, thermoplastic powders are more suitable for thicker coatings, providing increased chemical resistance and durability, while thermosetting powders are often used when comparatively thin coatings are desired such as decorative coatings. The principal resins used in thermoplastic powders are polyethylene, polyvinyl, nylon and fluoropolymer. Thermosetting powders use primarily epoxy, polyester and acrylic resins.

Powder coating virtually eliminates waste streams associated with conventional painting techniques. These waste streams include air emissions, waste streams generated from air emission control equipment, and spent cleaning solvents. Powder coating also greatly reduces employee exposure and liabilities associated with liquid coating (wet solvent) use. In addition, cleanup times are shorter because over spray can be readily filtered, classified, and reclaimed on site, regardless of the complexity of the system.

Care must be taken to not mix powders. Colored powders, unlike liquid coatings, will not blend together. This produces discrete colored dots in the final film. Different powder coating resins melt at different rates during curing and will produce "fisheyes" and/or voids in the coating film. In all cases, the dry powder is separated from the air stream by various vacuum and filtering methods and returned to a feed hopper for reuse. Powder coating total material efficiency (powder particles reaching the intended surface) of these systems can reach 95% with reclamation. Other advantages over conventional spray painting include greater durability; improved corrosion resistance; and elimination of drips, runs and bubbles.

Powder coatings are somewhat limited in their application to aerospace equipment. They typically are not used with primer systems that inhibit corrosion, but they can be successfully applied over many primed and pretreated metal substrates. If primers or pretreatments are not used, the powder coating provides protection as a barrier and prevents corrosion as long as it is intact and undamaged. The temperatures that are required to cure the coating are too high for many materials used in aerospace structures (primarily aluminum). However, recently developed formulations allow curing at as low as 250°F, which enables the use of powder coating on most materials. Powder coating can be implemented in high-production facilities with highly automated application systems or on low-volume, manually applied, batch-cured applications.

Specifications

The following table contains the specifications and parameters of the Organic Finishing Powder Coating Line.

Organic Finishing Powder Coating Line Specifications and Operating Parameters

Specification	Parameter
Part Size	Up to 2' x 6' x 4'
Batch Size	Small (6 lbs. of powder) to Medium (50 lbs.) to Large (500 lbs.)
Conveyor Speed	Variable, 2–12'/min
Cure Temperature	Variable, up to 450°F
Cure Time	Variable, no limit

Current Equipment Value

The following table contains the purchase cost and current equipment value of the Organic Finishing Powder Coating Line.

Original Purchase Cost and Current Equipment Value of the Organic Finishing Powder Coating Line

Purchase Cost	Current Value	Years of Service
$ 2,180,000	$ 726,667	8

Technology Benefits and Advantages

- Elimination of VOCs and HAPs used as solvents in paints eliminates hazardous air emissions
- Significantly reduced coating cure time (85%)
- Improved safety and health working conditions
- Material user efficiencies approach 95% since overspray can be captured, filtered and recycled
- Reduced energy requirements by recirculation of powder coating spray booth air
- Superior finish, greater durability, improved corrosion resistance, and elimination of drips, runs and bubbles
- Significant cost savings in labor, materials, handling, and disposal of waste
- Effectively employed in the commercial industry for 30 years and is a mature application technology
- New powder coating formulation developments include:
    - Combined IR/UV curing powders that can reduce overall curing time by 50% or better.
    - Close-coupled IR curing powders (NIR) that can keep substrate temperatues below 180°F due to the short cure cycle of the process (5–20 seconds).

Technology Limitations and Disadvantages

- Powder booth ventilation must be maintained to eliminate explosion hazards (accumulation of suspended particulate). Powder and air mixtures can be a fire hazard when an ignition source is introduced.
- System configurations are partially application-specific, but not severely limited.
- Depending on the system, some application limitations may apply such as intricate shapes and assembled components.
- Elimination of coating carrier solvents requires high-quality cleaning and pretreatment processing of parts.

DoD Need

Army: CM-3, P2-1

Air Force: 1261

Navy: 2.I.01.g, 2.I.01.q, 3.I.04.h

Recommended Upgrades for Continued DoD Support

Since the Organic Finishing Powder Coating Line was engineered and built, several improvements have taken place in powder coating technology, enhancing both the application control of the different coating materials, and opening the processing window for coating a wide variety of materials.

Recommendations for purchases to upgrade the Organic Finishing Powder Coating Line operations include the following items: higher-performance electrostatic applicators with voltage feedback control for more complex part coating; digital air logic and electrostatic control systems for improvement in automated powder application process engineering; UV curing lamp system for high-speed coating and select sensitive substrate coating applications such as magnesium castings and composite structures; and NIR curing tunnel system for sensitive substrate coating applications such as aluminum/plastic/fiberglass composite structures, lightweight magnesium castings, and maintenance/spot repair process development.

Organic Finishing Powder Coating Line

Representative NDCEE Tasks

Unitized Coating Application Facility, Electrocoat and Powder Coat (Tasks N.002, N.006, and N.046)

- Evaluated potential substitutes to coating systems containing VOCs and HAPs
- Demonstrated technologies to meet performance and production requirements

Evaluation of Powder Coating Technology for Small Arms Bullet Tip Identification (Tasks N.110 and N.212)

- Evaluated powder coating technologies for reduction in toxic emissions and VOCs, production cost reductions/benefits and increased transfer efficiency

Demonstration/Validation of Powder Coating for Hazardous Waste Minimization from Painting Processes at Rock Island Arsenal (Task N.130)

- Demonstrated powder coatings for elimination of VOCs, ODCs, and HAPs from coating process; increased production rates; decreased waste streams; and improved coatings performance

Potential Technology Transfer Applications

Powder coating has many potential avenues for use within the DoD. The potential for coating materials cost reduction, volatile solvent emissions elimination, no HAPs formulations, and reduced overall processing time and labor should provide sufficient incentive for use of these coatings. Use could include all small maintenance part coating activities and smaller coating facilities. Outsourcing of initial powder coating activities could provide immediate benefits, which include minimizing facilities capital expenditure and site VOCs, qualifying mil-spec powder coatings, and utilizing higher durability coatings while coating materials are integrated into military acquisition and maintenance systems.

Power Washer

Overview

The Power Washer is a closed-loop, high-pressure spray system used to clean and degrease parts that have a relatively simple geometry. A basket can be loaded with parts and lifted onto a rotating turntable by using a jib crane. An aqueous solution is pumped from a reservoir and spray-blasted via a rotating manifold of nozzles onto the parts. A fresh water or deionized rinse removes the solution from the parts before they are hot-air dried. The system also has a bath maintenance feature that uses a process in which suspended contaminants from the solution are removed via centrifugal action. An oil skimmer removes surface oils from the solution before it is recycled to the main reservoir. The solution then passes through another oil skimmer and filter located on the main reservoir. These bath maintenance features help extend the life of the cleaning solution in the reservoir.

Specifications

The following table contains the specifications and parameters for the Power Washer.

Power Washer Specifications and Operating Parameters

Specification	Parameter
Maximum Part Size	3' x 4' x 4'
Maximum Part Weight	5,000 lbs.
Temperature	80–190ºF
Variable Flowrate	Up to 350 gpm
Variable Pressure	20–200 psig

Current Equipment Value

The following table contains the purchase cost and current equipment value for the Power Washer.

Original Purchase Cost and Current Value for the Power Washer

Purchase Cost	Current Value	Years of Service
$150,000	$ 43,750	8.5

Technology Benefits and Advantages

- Contains PLC that can be programmed for a variety of times and temperatures for each stage of cleaning
- Performs heavy-duty degreasing of many types of components
- Reduces EHS issues associated with solvent cleaning
- Replaces hazardous solvents with an environmentally friendly aqueous cleaner
- Saves costs in labor, materials, handling and disposal of hazardous waste
- Recycles wash and rinse solutions after filtration, which reduces the wastestream quantity generated

Technology Limitations and Disadvantages

- The part geometries should be simple or medium in complexity for this system to provide the optimum cleaning (no small pin holes).
- The aqueous-based chemistry is not ideal for parts that are prone to rusting.

Recommended Upgrades for Continued DoD Support

The Power Washer is currently maintained in operational condition. Therefore, there are no recommended or required upgrades to the system at this time.

Representative NDCEE Task

Nonhalogenated Systems for Cleaning Metal Parts (N.007)

- Identified, tested, and evaluated the most environmentally compliant, technically and economically feasible nonhalogenated metal parts cleaning system for the widest range of DoD applications

Potential Technology Transfer Applications

This technology could be applied in a wide variety of cleaning and degreasing applications. This system is also transferable to those applications testing recycle and recovery equipment on aqueous cleaning solutions.

DoD Need

Army: CM-4

Navy: 2.I.01.g, 2.I.01.q, 3.I.11.b, 3.I.13.a, 3.II.03.a

Power Washer - Rear View

Power Washer - Front View

Reverse Osmosis Units

Overview

Reverse Osmosis has numerous functions in industry. It can be used for desalination of waters, boiler feed purification, dye purification, and coolant recovery. Reverse Osmosis is also used to reduce biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in waste streams before discharge. Other uses include recovery of some types of plating chemicals, heavy metals, and organics from aqueous solutions and rinse waters.

Reverse Osmosis is a high-pressure technology that separates ionic species. The process fluid is forced across a semipermeable membrane (sized from 1–20 Angstroms), where the composition and permeability of the membrane is dependent on the application. Membrane-permeable materials pass through to be collected in a water stream. Metals or chemicals can be recovered from the water stream, or the water stream can be concentrated and discarded as waste, as in process fluid purification applications.

The NDCEE Demonstration Facility has both a full-scale and a bench-scale Reverse Osmosis Unit.

Specifications

The following table contains the specifications and parameters for the Reverse Osmosis Units.

Reverse Osmosis Units Specifications and Operating Parameters

Specification	Parameter
Flow Rate	Full-scale unit - 5 gpm Bench-scale unit - 0.5 gpm
Operating Pressure	250–1000 psi
Membrane Material	Polyamide and other thin film composites
Material of Construction	316SS

Current Equipment Value

The following table contains the purchase cost and current equipment value for the Reverse Osmosis Units.

Original Purchase Cost and Current Value for the Reverse Osmosis Units

Purchase Cost	Current Value	Years of Service
$250,000	$104,167	7

Technology Benefits and Advantages

- Helps meet compliance with strict discharge regulations
- Reduces chemical costs and waste volume by purifying and recycling contaminated water
- Improves water quality
- Lowers operating costs for waste treatment and capital costs for chemicals
- Reduces hazardous waste

Technology Limitations and Disadvantages

- High-pressure system that is somewhat labor-intensive

Recommended Upgrades for Continued DoD Support

The full-scale and bench-scale Reverse Osmosis Units are maintained in a state from which operation could be restored in less than one man-day. Therefore, there are no recommended or required upgrades to the units at this time.

Representative NDCEE Task

Office of Industrial Technology Program Coordination (Task N.133)

- Removed NaCl from rinse waters for reuse of rinse waters

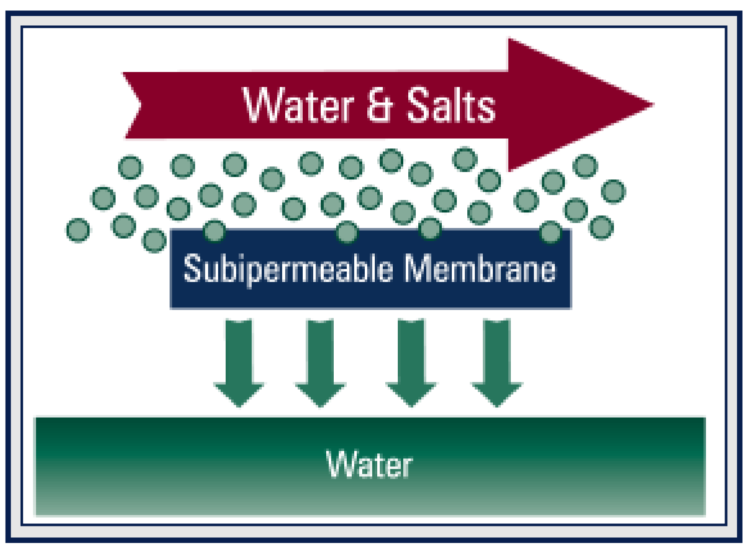
Potential Technology Transfer Applications

This technology could be applied in those applications that are looking to recover plating chemicals, metals, and organics from aqueous, spent bath solutions and rinse waters. This technology can also be applied in those applications that involve boiler feed purification and blowdown reclamation, dye purification, coolant recovery, and reduction of BOD and COD in waste streams.

DoD Need

Army: CM-7, CM-10, CM-5

Navy: 2.II.01.q, 3.I.03.b, 3.I.11.b, 3.I.11.j, 3.I.13.a



Reverse Osmosis Process

Solid Media Blast Station

Overview

The Solid Media Blast Station located in the NDCEE Demonstration Facility consists of a set of two standard industrial blast cabinets. Solid media, such as steel, alumina, and other grit and shot, is propelled by air against a coating to be removed. In addition, the equipment can be used for surface preparation of samples prior to application of pretreatments, paints, or other coatings.

Both blast cabinets are manufactured by Empire Abrasive Equipment Company. Each cabinet is equipped for operation using interior nozzles of various sizes and grit or shot to suit the application. A Torritt Model air filter serves both blast cabinets

The larger unit is a Model 7272, which can accommodate parts as large as 58" x 64" x 62" and weighing 1,000 lbs. The reclaimer is rated at 1200 CFM @ 10" S.P. Normally this cabinet is used to process parts requiring more aggressive processing. Alumina and steel grit are most commonly used.

The smaller unit used for less aggressive blasting is a Model 2636. Parts as large as 22" x 20" x 30" can be mounted in this cabinet. The reclaimer is rated at 400 CFM @ 6" S.P. Small, soft metal parts requiring glass bead media are usually processed.

Specifications

The following table contains the specifications and parameters for the Solid Media Blast Station.

Solid Media Blast Station Specifications and Operating Parameters

Specification	Parameter
Maximum Part Size (Model 7272)	58" x 64" x 62"
Maximum Part Size (Model 2636)	22" x 20" x 30"
Reclaimer Rate (Model 7272)	1200 cfm @ 10" S.P.
Reclaimer Rate (Model 2636)	400 cfm @ 6" S.P.
Blast Pressure	20–90 psi
Media Mesh Sizes	8–440

Current Equipment Value

The following table contains the purchase cost and current equipment value for Solid Media Blast Station.

Original Purchase Cost and Current Value of the Solid Media Blast Station

Purchase Cost	Current Value	Years of Service
$30,041	$10,017	8 (for each piece)

Technology Benefits and Advantages

- Improves depainting efficiency; removal can be accomplished in a fraction of the time
- Eliminates use of toxic chemicals
- Meets stringent air pollution requirements
- Is more cost effective than sandpaper because of recyclable blast media
- Simplifies work process resulting in decreased labor costs due to work being able to be completed by lower-level personnel
- Removes dust to the outside via ventilation system filters

Technology Limitations and Disadvantages

- Government approval permits and documents may be needed.
- Appropriate solid media is needed for the process.
- Waste disposal includes both the coatings removed and spent media.

Recommended Upgrades for Continued DoD Support

The Solid Media Blast Station is currently maintained in operational condition, or in a state from which operation could be restored in less than one man-day. Therefore, there are no recommended or required upgrades to the equipment at this time.

Representative NDCEE Tasks

Sustainable Green Manufacturing (Tasks N.213 and N.301)

- Preparing surfaces prior to ion vapor deposition of coatings

Materials and Processes Partnership for Pollution Prevention (Task N.227)

- Preparing surfaces prior to ion vapor deposition of coatings

Corrosion Measurement and Control (Tasks N.255 and N.304)

- Preparing surfaces prior to ion vapor deposition of coatings

Potential Technology Transfer Applications

This technology could be applied in coatings removal applications.

DoD Need

Air Force: 120, 225, 580, 814, 988, 1468

Army: CM-3, P2-1

Navy: 3.I.05.a

Solid Media Blast Station

Supercritical CO_2 Cleaning System

Overview

The Supercritical Carbon Dioxide (CO_2) Cleaning System is a high-pressure cleaning process that takes advantage of the fact that CO_2 is an extremely effective solvent for many organic materials, once in its supercritical state. It is a cleaning process that penetrates small openings and is especially useful for precision or intricate components like gyroscopes, accelerometers, nuclear valve seals, laser optic components, special camera lenses, electromechanical assemblies, and porous ceramics. The process works well in removing liquid contaminants, including silicone, petroleum and dielectric oils, flux residues, lubricants, adhesive residues, and fats and waxes. However, it is not very effective on heavy soils, or for the removal of particles or salts, except in circumstances where it is used in conjunction with agitation or ultrasonic cleaning.

CO_2 is probably the most widely used fluid in supercritical cleaning applications. CO_2 is especially useful, because it is nontoxic, nonflammable, and nonozone-depleting; has a supercritical temperature near ambient temperatures (good for temperature sensitive parts); and exhibits excellent solvent properties in its supercritical state. CO_2 supercritical cleaning does require high operating pressures in the range of 8–12 MPa, but operating temperatures of only 35–65°C. As a result, most supercritical cleaning equipment has been designed for high-pressure operation and is relatively small. High-pressure cylindrical chambers of supercritical cleaning equipment are intended to hold primarily small, intricate parts or parts with deep crevices, tiny holes, or very tight tolerances that normal alternative precision cleaning processes, specifically aqueous or semiaqueous processes, have difficulty cleaning.

To clean a component using supercritical CO_2, the part is placed in a sealed pressure vessel, which is then filled and flushed with the supercritical fluid. The contaminant-laden stream of CO_2 flows to a separator vessel where it is expanded to a gaseous state. At the lower pressure, the contaminants drop out of solution, allowing for easy separation from the supercritical fluid. The CO_2 is vented to the atmosphere or up to 90% of the gas can be recovered and reused in a closed loop system. In either case, the CO_2 does not contribute to the waste stream; thus, all treatment and disposal costs are associated with the contaminants only.

Specifications

The following table contains the specifications and parameters of the Supercritical CO_2 Cleaning System.

Supercritical CO_2 Cleaning System Specifications and Operating Parameters

Specification	Parameter
Large Cleaning Chamber	5000 psi maximum working pressure
Small Cleaning Chamber	3000 psi maximum working pressure
Low Pressure Receiver	300 psi maximum working pressure
High Pressure Receiver	6000 psi maximum working pressure
Electrical Requirements	
Supercritical CO_2 System	480 V., 60 Hz., 3 Phase, 40 A
CO_2 tank	480 V., 60 Hz., 3 Phase, 14 A
Shop Air Requirements	120 psi, 1/2" or 3/4" line
Cooling Water Requirements	2 gpm min., 80°F max., 40 psi min., 120 psi max.

Current Equipment Value

The following table contains the purchase cost and the current equipment value of the Supercritical CO_2 Cleaning System.

Original Purchase Cost and Current Value of the Supercritical CO_2 Cleaning System

Purchase Cost	Current Value	Years of Service
Donated to the NDCEE	Not Applicable	4

Technology Benefits and Advantages

- Nontoxic surface cleaning and degreasing properties
- Ability to clean complex parts
- Relatively short cleaning times
- Equally high degree of cleanliness to alternate technologies
- Completely dry components following cleaning at room temperature
- Typically closed loop systems
- High level of recycled CO_2

Technology Limitations and Disadvantages

- High capital costs
- Poor removal of hydrophilic contaminants
- High-pressure operations
- Limited component size
- Process parameters that have to be optimized for each specific application and type of contaminant

Recommended Upgrades for Continued DoD Support

The Supercritical CO_2 Cleaning System that is currently housed in the NDCEE Demonstration Facility is a research system and not intended for production type environments. Currently there are no recommended upgrades for this unit.

Representative NDCEE Task

Sustainable Green Manufacturing - Coatings and Removal Research and Engineering Supercritical CO_2 Cleaning Demonstration and Validation (Task N.213, Subtask R3-2)

- Evaluating CO_2 as a precision cleaning technology for selected metals
- Determining critical parameters for precision cleaning, including cycle time and liquid flush requirements

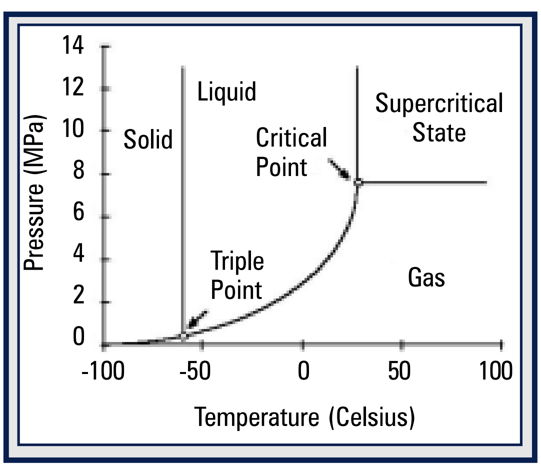
DoD Need

Army: CM-4

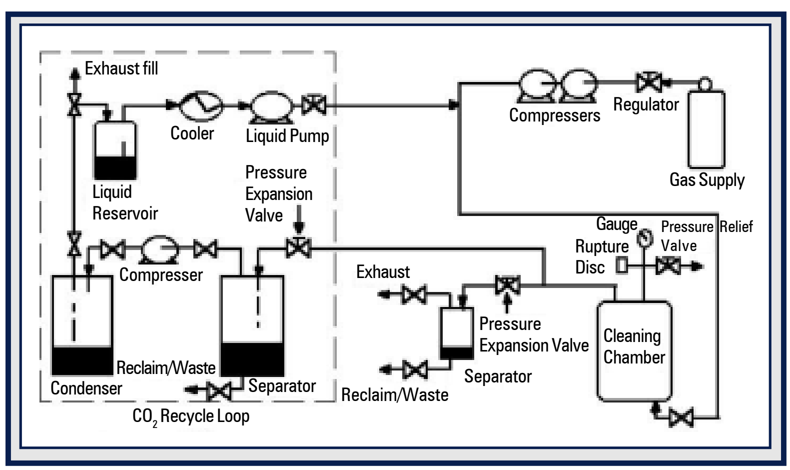
Navy: 2.I.01.g, 2.I.01.q, 3.I.14.a, 3.II.03.b

Potential Technology Transfer Applications

Due to the early stages of this technology and the prototype-based design of the current Supercritical CO_2 Cleaning System housed at the NDCEE Demonstration Facility, this unit would not currently be a candidate for technology transfer. However, as this technology is further developed, the equipment may have the potential to be transitioned to any facility performing, but not limited to, the cleaning of radar connectors, transformers, cables, laser optical benches and o-rings, electronics, optics and silicon chips.



CO_2 Phase Diagram



Typical Supercritical CO_2 Cleaning System

Supercritical CO_2 Coating System

Overview

In the pursuit of lower-VOC coating formulations, Supercritical Carbon Dioxide ($SCCO_2$) can be used to replace carrier solvents in many applications. Liquefied CO_2 and coatings are mixed under pressure and sprayed out of a special atomizing paint applicator. The liquid CO_2 decompresses rapidly upon exposure to ambient pressure providing a fine atomization of the coating. This produces a coating finish equal to that of high-volume low-pressure (HVLP) applications.

This technology is used as both a coating application replacement and as a dispersing agent. It is a safe and effective technology that significantly reduces VOCs and associated hazards of low solids coatings.

Successful uses of this technology have been with applications of simpler one-component coating systems and pure materials such as edible oils and cleaner/degreaser formulations. VOC levels can be cut by up to 90% when CO_2 is used as a dispersing or thinning agent. Coatings are applied under supercritical conditions of 1600 psi and 35°C but quickly assume room temperature due to the fine atomization of the spray. This instantaneous decompression of the liquefied CO_2 produces a very confined hazard area of high pressure and the final spray condition appears like an aerosol spray. This technology allows for application of very thin films and coatings.

Current known commercial applications include application of cooking oil to breaded chicken and fish patties, light protective oiling of three-dimensional surfaces, and dispersing agent for sol-gel coatings.

DoD Need

Army: CM-3, P2-1

Air Force: 805, 1261

Navy: 2.I.01.g, 3.I.04.h

Use of $SCCO_2$ technology for coating VOC reduction has been limited due to CO_2's solubility differences with the coating's resin system and remaining intermediate solvents. This solubility difference is further enhanced by use of high-organic solid levels and multiple-component coating systems. It has been suggested that formulations could be tailored to reduced solids, being that the majority of coating solvent and subsequent VOCs would be displaced by CO_2; but this approach has been limited by regulated solids content levels in military and industrial coatings. By increasing CO_2 levels, total application pressures could be reduced and limit the solubility differences in coating.

Initial coating formulations need to be customized (removal of fast solvents at manufacturing point) and intermediate solvents added to produce a pumpable viscosity formulation. Two-component systems will also have to be checked for proper resin-to-catalyst ratios in order to control pot life and dry times. While CO_2 acts as a fast solvent for the system, it is still far more compressible than the solvent it replaces and provides little volume dilution (separation) between reactive components.

$SCCO_2$ Spray System

Operators of the $SCCO_2$ Coating System (produced by Linden EMB) require a significant amount of training to determine optimum operating conditions for each coating system. Troubleshooting system problems and flushing out the system after each use are critical due to the higher reactivity of some coatings and potential loss of the supercritical pressure and temperature conditions of CO_2.

Specifications

The following table contains the specifications and parameters for the $SCCO_2$ Coating System.

$SCCO_2$ Coating System Specifications and Operating Parameters

Specification	Parameter
Operating Temperature(s)	35–60°C
Operating Pressure	1200–1800 psi
Flow Rate	500 cc/min.
Minimum Part Size	None
Maximum Part Size	6' x 4' x 3'
Maximum Part Weight	250 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value for the $SCCO_2$ Coating System.

Original Purchase Cost and Current Value of the $SCCO_2$ Coating System

Purchase Cost	Current Value	Years of Service
$93,000	$62,000	4

Technology Benefits and Advantages

- Reduces VOC levels significantly in coatings and other applied materials
- Reduces coating costs significantly (Liquid CO_2 = $1.70/gallon vs. solvent $5–$10/gallon)
- Works with a variety of coating formulations
- Surpasses HVLP spray coating quality
- Applies coatings very rapidly (high lay-down rate) due to quick release of CO_2
- Has potential to improve transfer efficiency of coatings (controlled atomization)
- Recirculates simple formulations without performance loss
- Reduces environmental impact associated with hazardous solvents and solid/hazardous waste that is generated for disposal
- Improves health and safety working conditions and decreases health-related costs (liability risks, protective equipment costs, and monitoring costs) compared to the use of VOC-containing coatings
- Reduces manufacturing costs as a result of less raw material usage due to higher transfer efficiency
- Produces higher coating delivery rates, reducing overall application time due to lower compressed CO_2 liquid volume in applied coating

Technology Limitations and Disadvantages

- Technology requires complex knowledge of coatings interaction with CO_2.
- Coatings need to be reformulated to remove fast solvents.
- A solvent is still required to flush out the system (can be reused).
- Fine applicator nozzles can plug quickly.
- Capital costs are moderate to high.
- Maintenance costs can be high.

- Extensive equipment training is needed.
- Cleaning of the equipment is more time-consuming than other processes.

Recommended Upgrades for Continued DoD Support

The $SCCO_2$ Coating System currently meets or exceeds modern industry standards. The equipment is maintained in operational condition. Currently, there are no recommended or required upgrades to the $SCCO_2$ Coating System.

Representative NDCEE Task

UNICARB CO_2 Painting Demonstration for Rock Island Arsenal (RIA) (Task N.205)

- Ongoing effort to develop a methodology for applying Chemical Agent Resistant Coating using the UNICARB system

Potential Technology Transfer Applications

Potential technology transfer sites would include those facilities that are currently looking to reduce HAP and VOC air emissions by the elimination of solvents in coatings applications.

Ultrahigh-Pressure Waterjet

Overview

Unlike conventional technologies that use toxic chemicals, abrasive media blasting or thermal energy to clean parts and remove coatings, the Ultrahigh-Pressure Waterjet (UHPWJ) uses highly pressurized deionized water.

The UHPWJ is used for precision industrial applications such as cutting, cleaning, degreasing, debonding, decoating and depainting. It can be a rapid, cost-effective and environmentally safe alternative that avoids pollution and disposal drawbacks of machining, vapor degreasing, grit blasting and chemical baths.

The UHPWJ is a robotically controlled, closed-loop system that uses a low-volume stream of pure water at high pressures. The stream is manipulated by a 6-axis, Fanuc high-precision, industrial pedestal robot. Various rotating blast nozzles that are specifically designed to provide the correct energy pattern are utilized for coating removal. Water is supplied to the nozzle assembly by an ultrahigh-pressure, dual-intensifier pump.

To minimize down time, a turntable for parts is equipped with quick-change toggle clamps to rapidly position and secure work pieces.

An operator controls the robot, pump and turntable with a user-friendly, menu-driven computer workstation. A teach pendant is used to program the robot's motion.

A water treatment system filters out particles larger than 0.35 microns before the water is used again for stripping or cleaning.

Specifications

The following table contains the specifications and parameters of the UHPWJ.

UHPWJ Specifications and Operating Parameters

Specification	Parameter
Operating Temperature	75°F, 21°C
Operation Pressure	25,000–55,000 psi
Flow Rate	<2 gpm
Maximum Part Size	6' x 6' x 6'
Maximum Part Weight	1,000 lbs.

Current Equipment Value

The following table contains the purchase cost and current equipment value of the UHPWJ.

Original Purchase Cost and Current Value of the UHPWJ

Purchase Cost	Current Value	Years of Service
$ 1,200,000	$ 154,286	8

Technology Benefits and Advantages

- Hazardous waste is reduced by 90%.
- Individual coating layers may be selectively removed with adjustments.
- Prewashing and masking are not needed in most applications.
- A process water reclamation unit captures removed coatings and returns water to the appropriate cleanliness levels for further blasting.
- Process material costs are reduced significantly.
- Labor hours are reduced by 50% for coating removal process.
- No dust or airborne contaminants are generated.
- Specific additives will control flash rusting and give long-term protection.

Technology Limitations and Disadvantages

- Capital costs are high.
- Operator training is required.
- Water can penetrate and/or damage joints, seals and bonded areas.
- Stripping rate varies with the type of paint, coating condition and coating thickness.
- This technique is not appropriate for composite or honeycomb thin-skinned materials.
- The medium-pressure water stripping process works well as a supplement to chemical paint stripping, but is not recommended as a stand-alone paint removal process for complete aircraft stripping. It has many successful applications as a part/component stripping process. Medium-pressure water without abrasive additives, such as sodium bicarbonate, will not always remove paint completely.
- The characteristics of the coatings to be removed may impact personal protection and waste collection/disposal considerations.

DoD Need

Army: CM-4, CM-9

Navy: 2.I.01.g, 3.I.05.a

Air Force: 1232, 120, 225, 311, 814, 988, 1468

Recommended Upgrades for Continued DoD Support

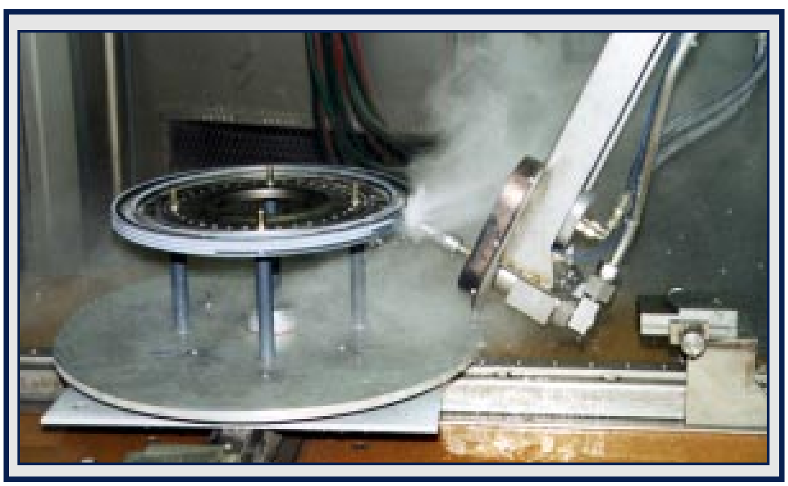
The UHPWJ cell currently meets or exceeds modern industry standards. The equipment is maintained in operational condition, or in a state from which operation can be restored in less than one-man day. Currently, there are no recommended or required upgrades to the UHPWJ cell.

Representative NDCEE Tasks

Automated Ultrahigh-Pressure Waterjet System Workcell (Task N.020)
- Removed flame spray coatings from jet engine components
- Removed paint from aircraft fuselage
- Removed metallic flame spray coatings from helicopter engine components
- Conducted software and hardware training for operators and maintenance personnel

New Attack Submarine Support (Task N.087)
- Evaluated, tested, and demonstrated alternative acid etching process of soft tiles

Stripping Methods for Soft Material Tiles on Submarines and Surface Ships (Task N.122)
- Removed soft materials from submarines and surface ships
- Developed vacuum recovery capability



UHPWJ robot removing flame spray coating.

Potential Technology Transfer Applications

The UHPWJ process equipment would be a candidate technology to be transitioned/implemented at any DoD facility that is currently removing coatings from small- to medium-sized components. Additional applications include rubber tire removal from roadwheels, sonar dome cutting, and flame spray removal.

UHPWJ with robotic arm and turntable

Vacuum Evaporator

Overview

Vacuum evaporation is a separation process that is typically used to recover plating chemicals from rinse water or to concentrate wastes from wastewaters. The concentrated wastes may then be either discarded or recovered.

Vacuum evaporation is based on a simple principle to separate water from salts and metals. Water vaporizes at 212°F, while dissolved salts and metals do not. Unfortunately, some chemicals degrade at this temperature. In a vacuum, however, water boils at lower temperatures, so water and chemicals can be separated without degradation of the chemicals. Both the water and the chemicals can then be reused.

Specifications

The following table contains the specifications and parameters for the Vacuum Evaporator located in the NDCEE Demonstration Facility.

Vacuum Evaporator Specifications and Operating Parameters

Specification	Parameter
Flow Rate	2 gph water
Material of Construction	316SS

Current Equipment Value

The following table contains the purchase cost and current equipment value for the Vacuum Evaporator.

Original Purchase Cost and Current Value for the Vacuum Evaporator

Purchase Cost	Current Value	Years of Service
$13,700	$5,708	7

Technology Benefits and Advantages

- Reduces aqueous waste
- Reduces hazardous waste
- Reduces the cost of hazardous waste disposal
- Reduces the cost of drums for hazardous waste disposal
- Can operate unattended

Technology Limitations and Disadvantages

- Technology requires a utility hookup for electricity and may require utility hookups for gas and cooling water.
- Technology may require an air permit for a gas burner (new source) and for evaporation to atmosphere.
- Units require operator training.
- Units must be installed in areas with fire suppression systems.

Recommended Upgrades for Continued DoD Support

The Vacuum Evaporator currently meets or exceeds modern industry standards. The equipment is maintained in operational condition. Currently there are no recommended or required upgrades to the system.

Representative NDCEE Tasks

The Vacuum Evaporator has been used to process wastewater from the closed loop plating line, which was operating under the following tasks:

Environmental Metal Plating Alternatives - Electroless Nickel Plating Rejuvenation (Task N.089)

- Evaluated technologies capable of reducing the amount of waste generated by electroless nickel plating processes

Evaluation of Noncyanide Silver Plating (Task N.104)

- Evaluated commercially available noncyanide alternatives to silver plating processes

Materials and Process Partnership for Pollution Prevention/Pollution Prevention Initiative (Task N.227)

- Evaluated commercially available noncyanide alternatives to copper and silver plating processes

Alloy Plating to Replace Cadmium on High-Strength Steels (Task N.000-02, Subtask 7)

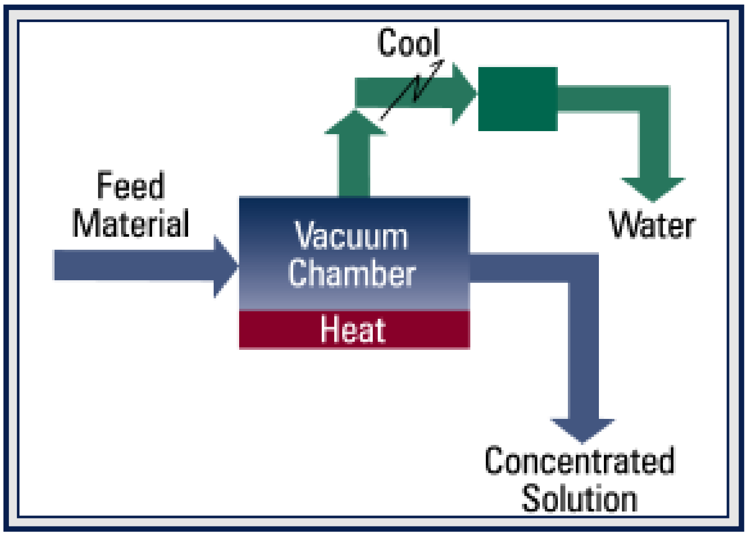
- Evaluated commercially available noncyanide alternatives to cadmium plating processes

Potential Technology Transfer Applications

This technology could be applied in those applications that are looking to recover plating chemicals from rinse water or to concentrate wastes from wastewaters.

DoD Need

Navy: 3.I.03.b, 3.I.11.b, 3.I.11.j, 3.I.13.a



Vacuum Evaporator Diagram

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